Space Science Enterprise Workshop (SSE)

Remote Sensing, In Situ and Sample Return

June 6, 2000

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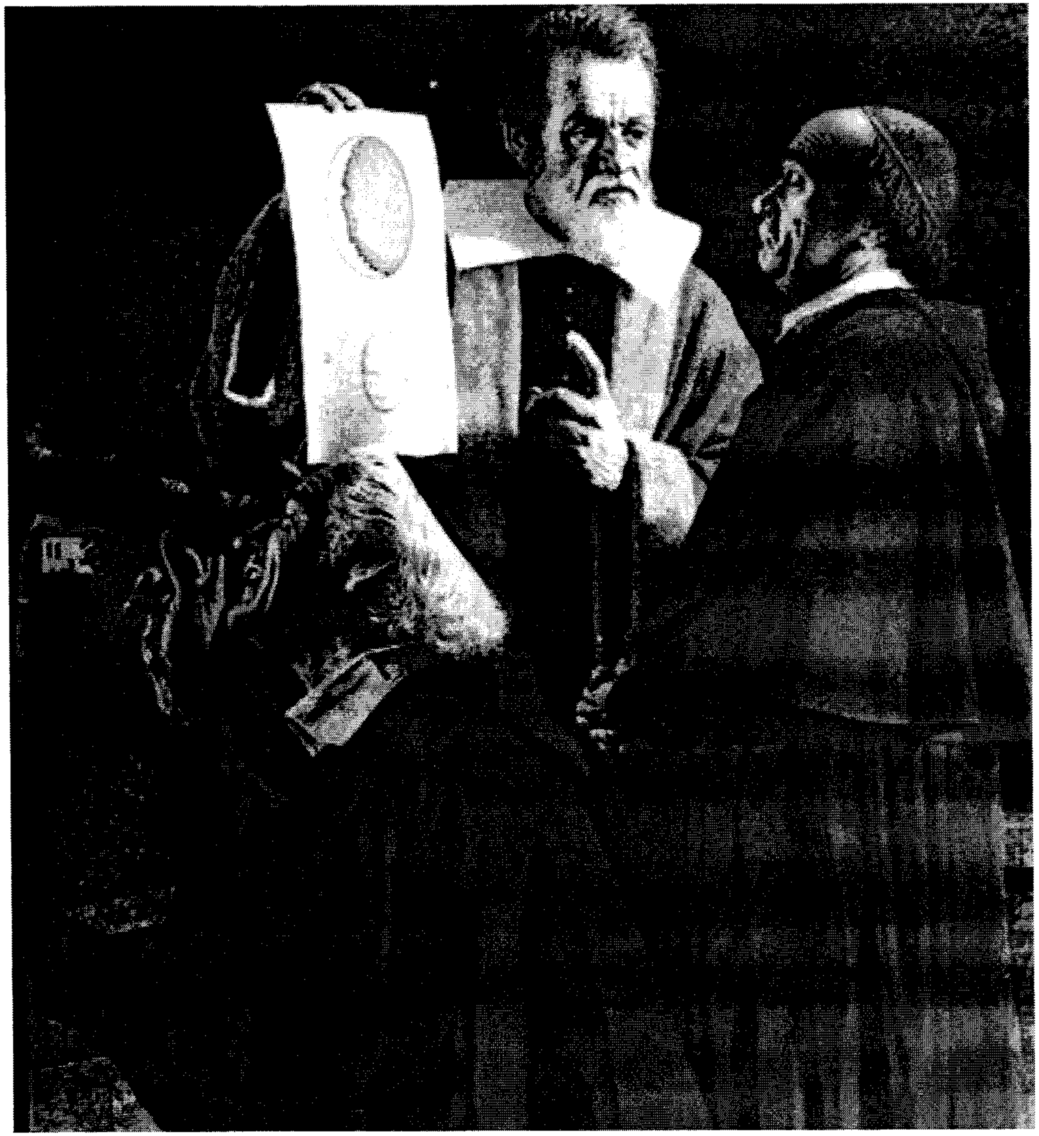
California Institute of Technology
Pasadena, California

- **Purpose of Space Science is to understand our environment using whatever means are available**
- **Basically two approaches**
  - **Remote Sensing**
  - **In Situ (or Sample Return)**
    - **Solids, surfaces, atmospheres**
    - **Interplanetary and interstellar - fields and particles**
- **Will discuss these sequentially**

Remote Sensing

- Began with measurement of star positions using astrolabes, etc. in prehistoric times
- Galileo introduced telescope - images of Jupiter's moons
- Newton discovered properties of prisms - led to spectroscopy
- Bigger telescopes gave more sensitivity and therefore range
- Went into space, starting in 1960 - first US launch (Explorer 1) did "in situ" not remote sensing

Galileo and His Telescope



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6/6/00

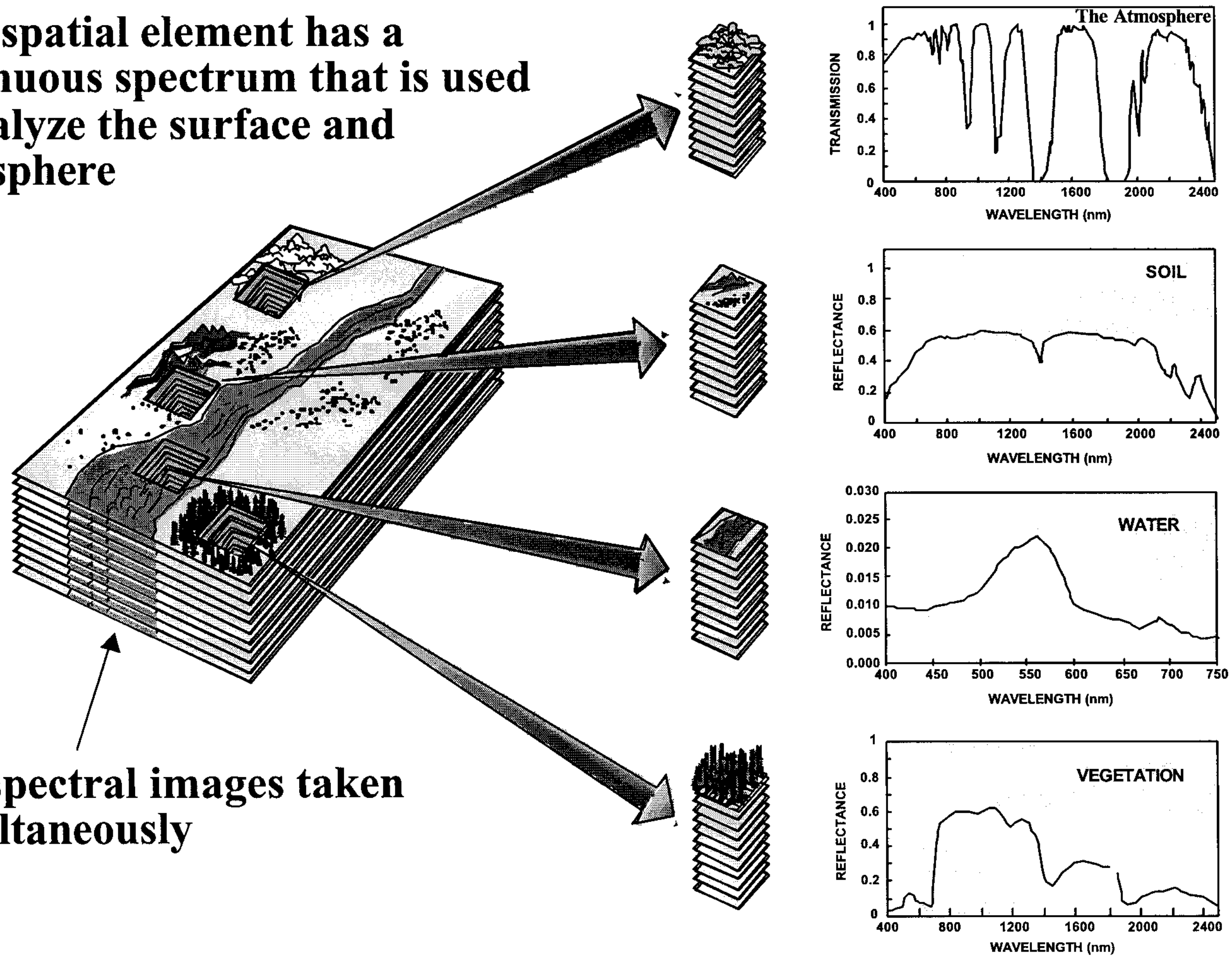
What Is Measured - *Photons*

- ***Photons*** come in different ***Energies*** (colors/wavelengths), ***Quantities*** and from ***Different places*** (spatial distribution)

- Imagers (Cameras), Spectrometers and Radiometers all measure photons or electromagnetic radiation
  - ***Spatial distribution*** is measured by Imagers
  - ***Energy*** (color) is measured by Spectrometers
  - ***Quantity*** (power) is measured by Radiometers

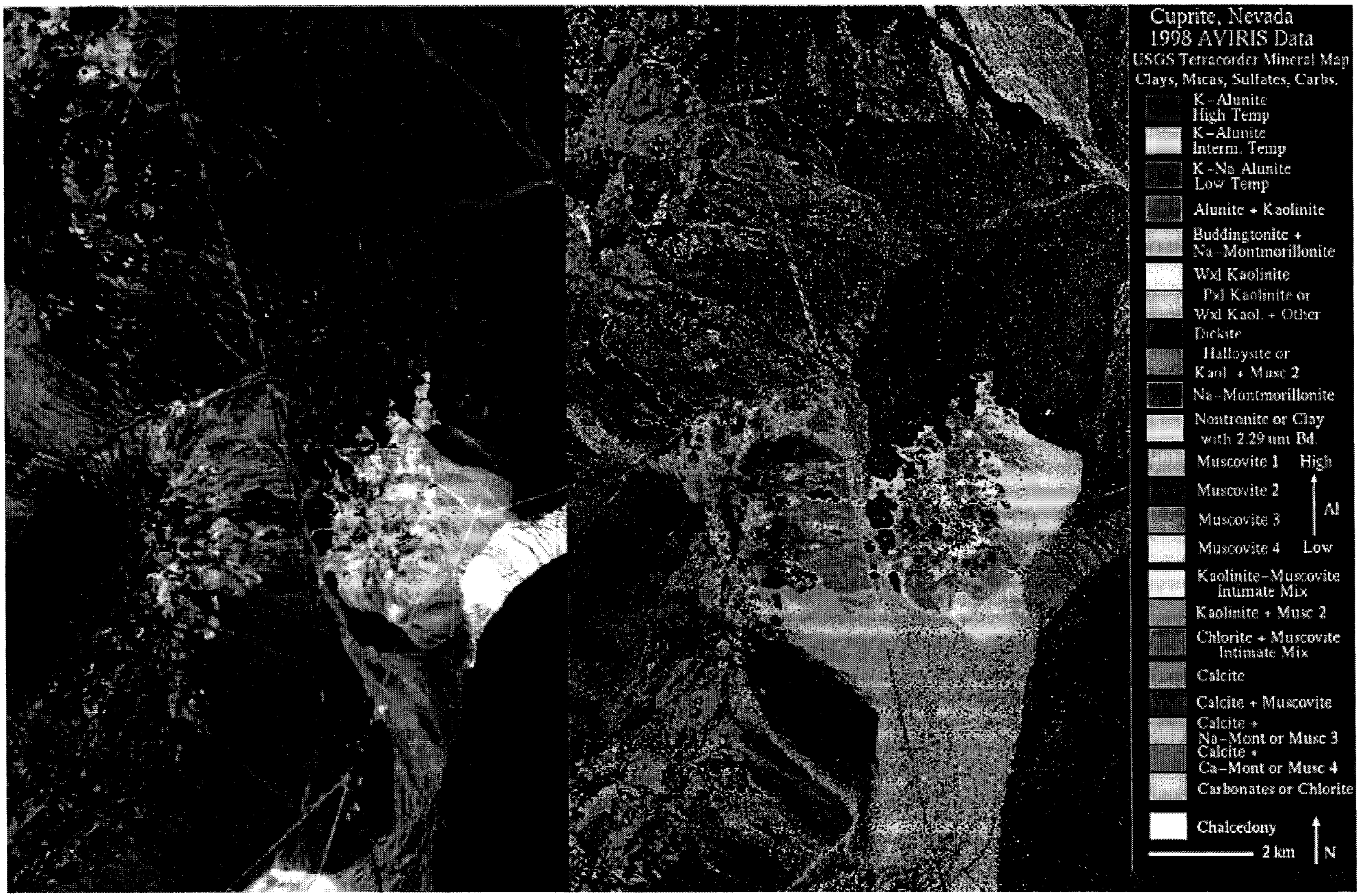
AVIRIS Concept

Each spatial element has a continuous spectrum that is used to analyze the surface and atmosphere



224 spectral images taken simultaneously

AVIRIS Data


Cuprite, Nevada
1998 AVIRIS Data
USGS Tetracorder Mineral Map
Clays, Micas, Sulfates, Carbs.
K-Alunite High Temp
K-Alunite Interm. Temp
K-Na Alunite Low Temp
Alunite + Kaolinite
Buddingtonite + Na-Montmorillonite
Wxl Kaolinite
Pxl Kaolinite or Wxl Kaol. + Other
Dickite
Halloysite or Kaol + Musc 2
Na-Montmorillonite
Nontronite or Clay with 2.29 um Bd.
Muscovite 1
Muscovite 2
Muscovite 3
Muscovite 4
High
Al
Low
Kaolinite-Muscovite Intimate Mix
Kaolinite + Musc 2
Chlorite + Muscovite Intimate Mix
Calcite
Calcite + Muscovite
Calcite + Na-Mont or Musc 3
Calcite + Ca-Mont or Musc 4
Carbonates or Chlorite
Chalcedony
2 km
N

What Is Measured - *Photons*

Where do the Photons come from...

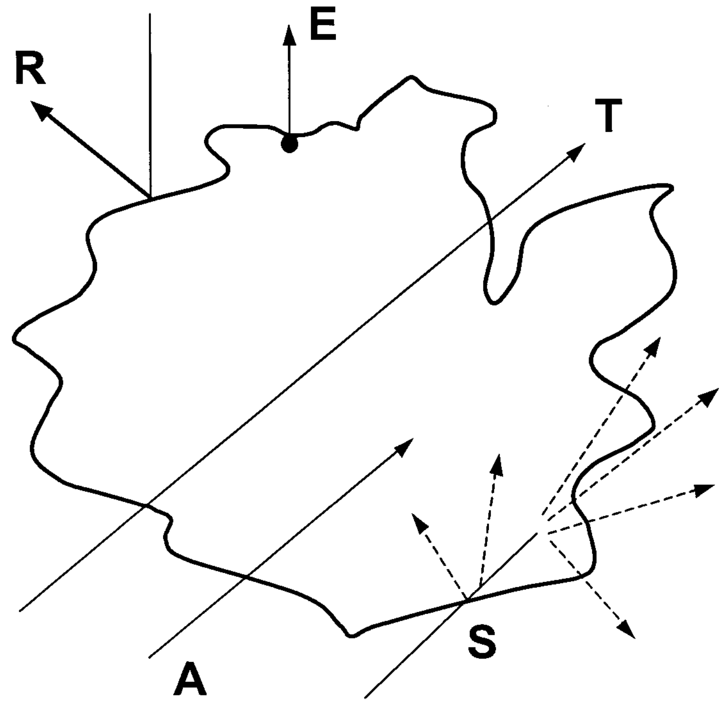
- There are a variety of sources for the photons we measure:
  - Blackbody radiation - stars, hot gasses, filaments
  - Energy absorption and re-emission; typically this has highly unique characteristics e.g., aurora borealis, lasers, Cherenkov radiation, etc.
- Most local radiation is blackbody - solar

Blackbody Example

- Blackbody radiation is described by Plank's formula
- Each physical mechanism has its own description; the instrument designer should understand the basic physics for the radiation to be observed

Mechanisms

- Emission (E)
- Reflection (R)
- Scattering (S)
- Transmission (T)
- Absorption (A)



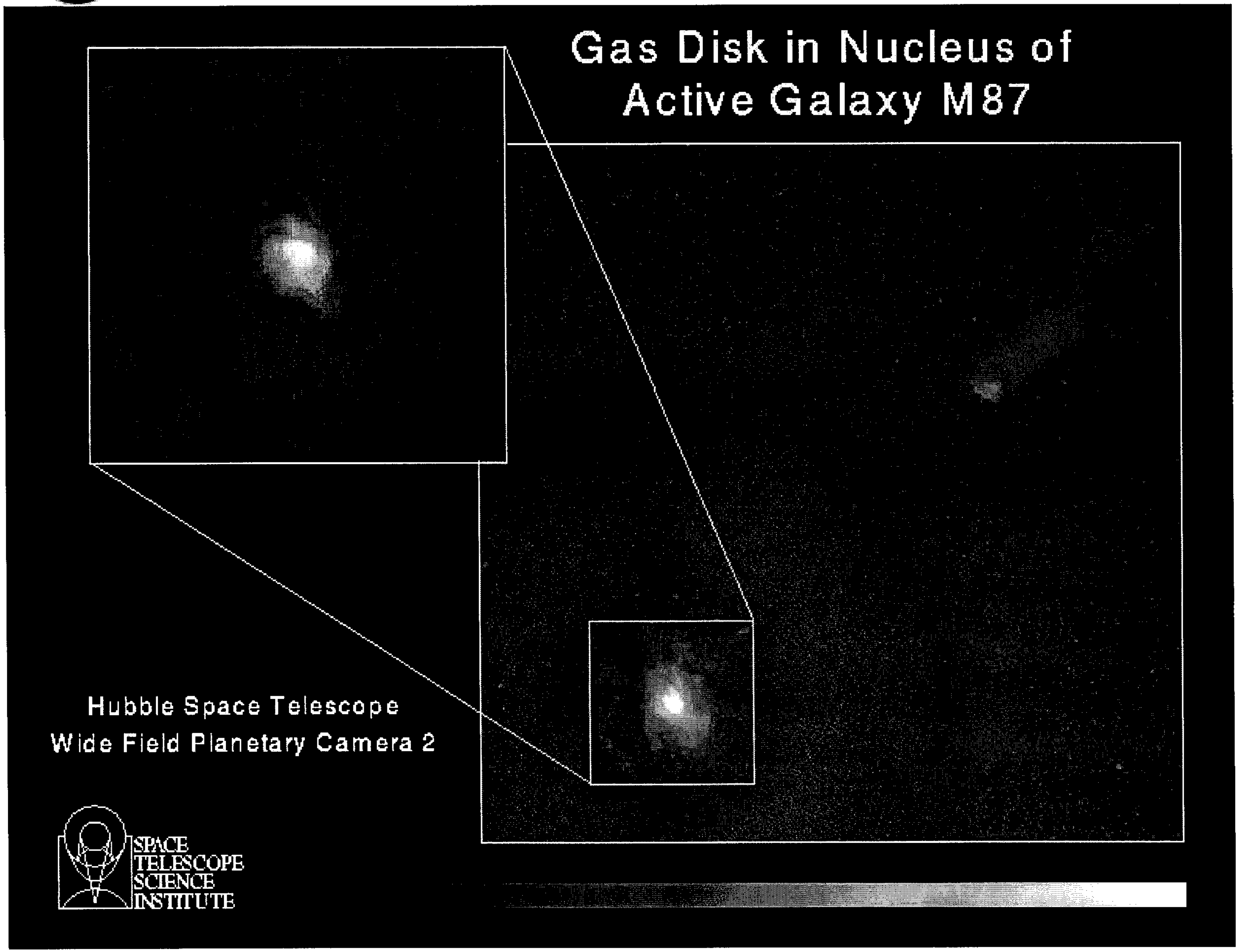
Why Make the Measurement ?

- To understand our physical surroundings, both close to us - on Earth, and at intergalactic distances
- The uses vary from weather forecasting, to testing the fundamental theories of physics; from land utilization to checking for life on other planets and elsewhere in the universe
- Scope is virtually unlimited ...

Why Make the Measurement from Space ?

- Earth applications
  - High area coverage rates
  - Global data sets
  - “Open Sky” - few international constraints
- Outward looking applications
  - No atmospheric distortion issues
  - 4π solid angle coverage

Russian Area 51


Gas Disk in Nucleus of
Active Galaxy M87
Hubble Space Telescope
Wide Field Planetary Camera 2
SPACE
TELESCOPE
SCIENCE
INSTITUTE

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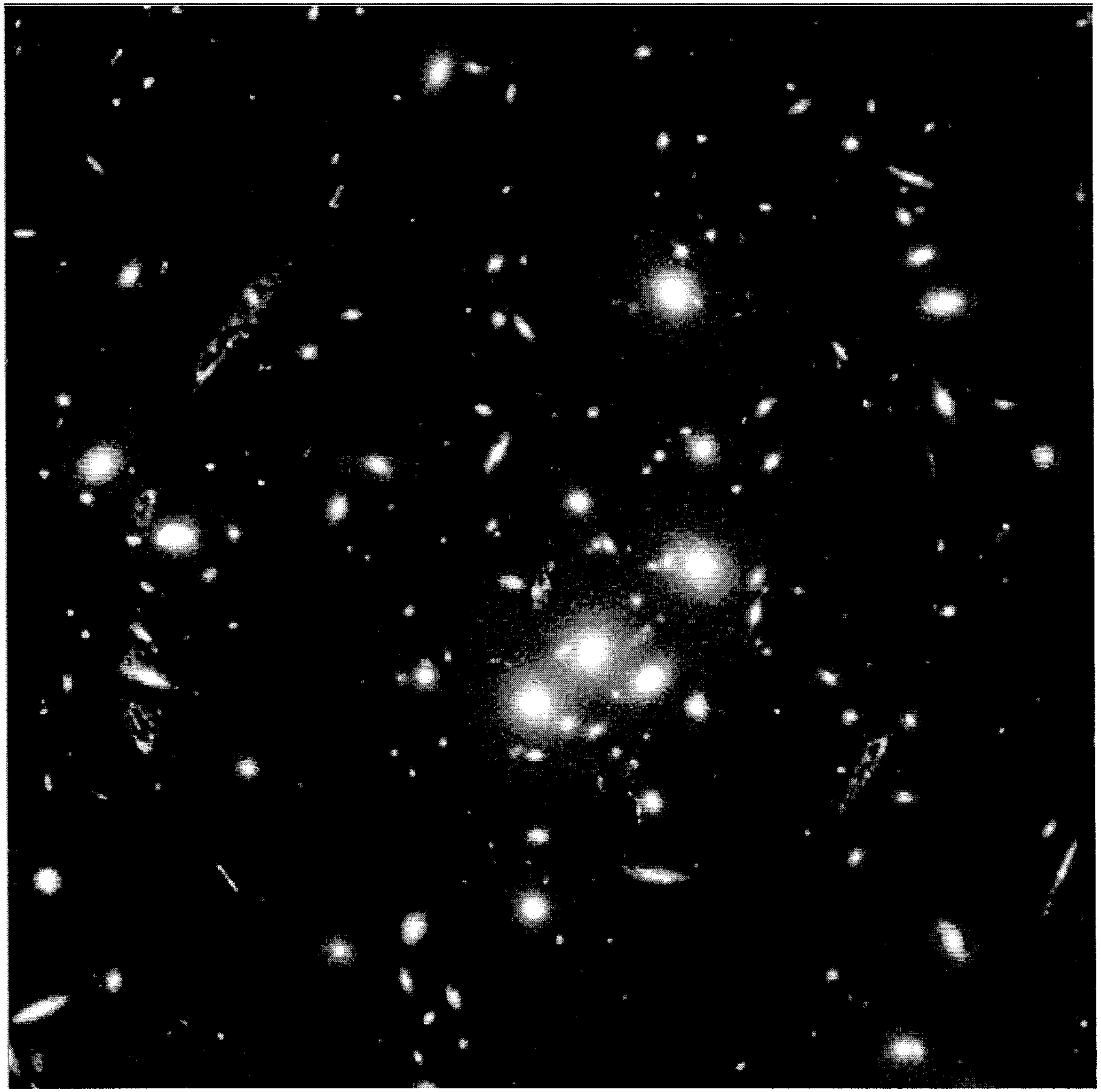
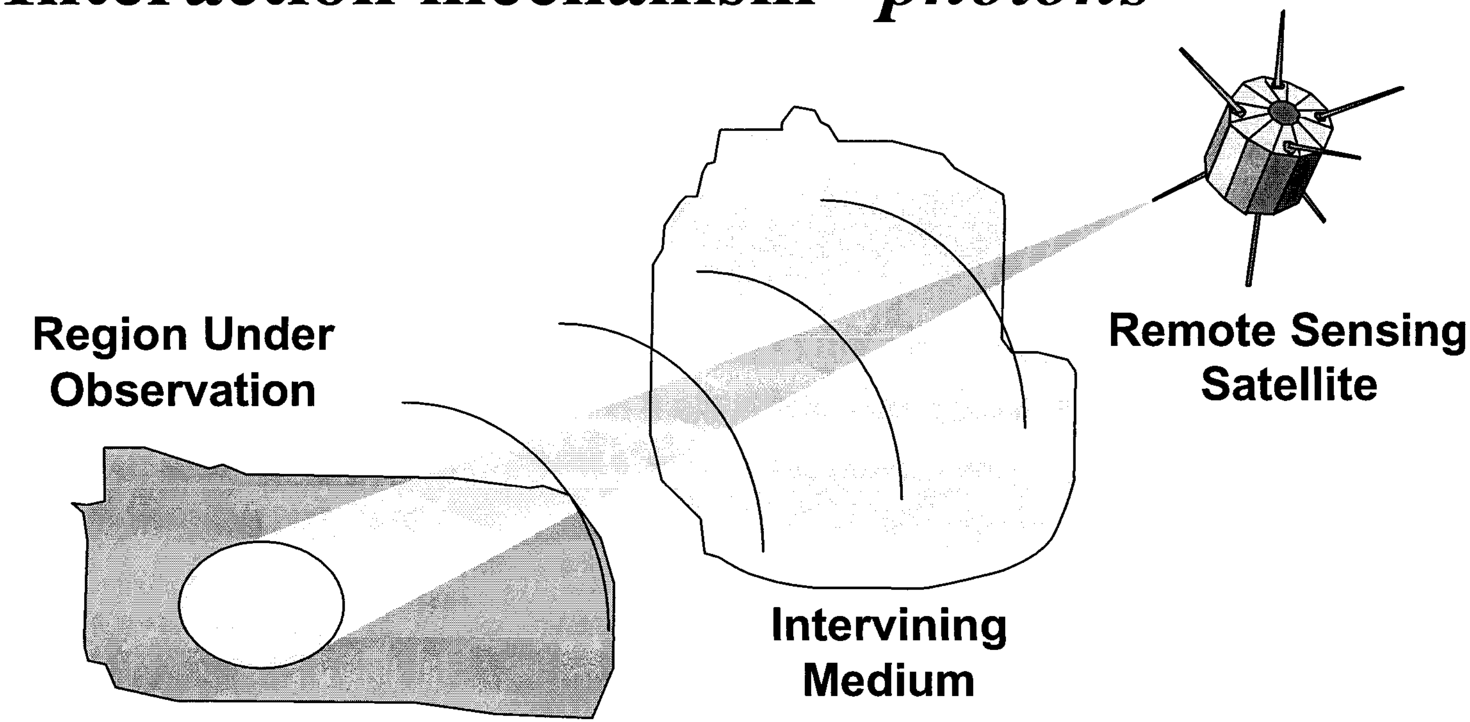
6/6/00

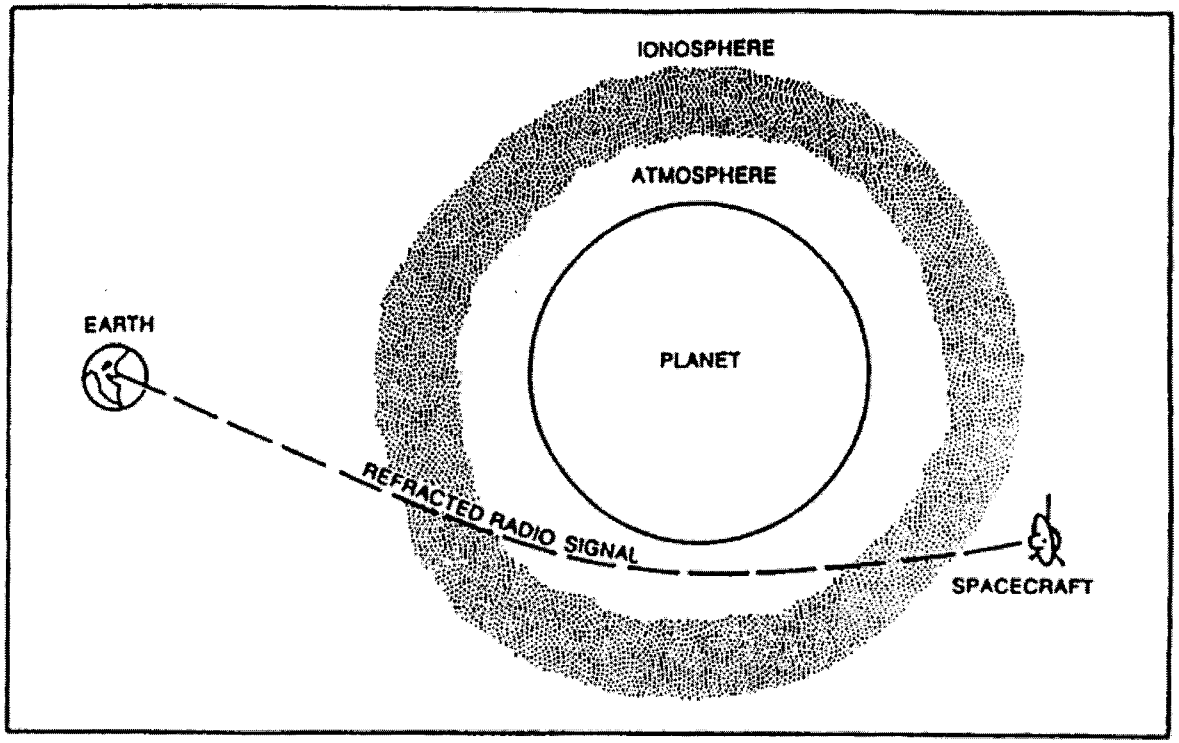


How - Remote Sensing

- **Acquisition of information about an object without direct physical contact**
- **Interaction mechanism - *photons***

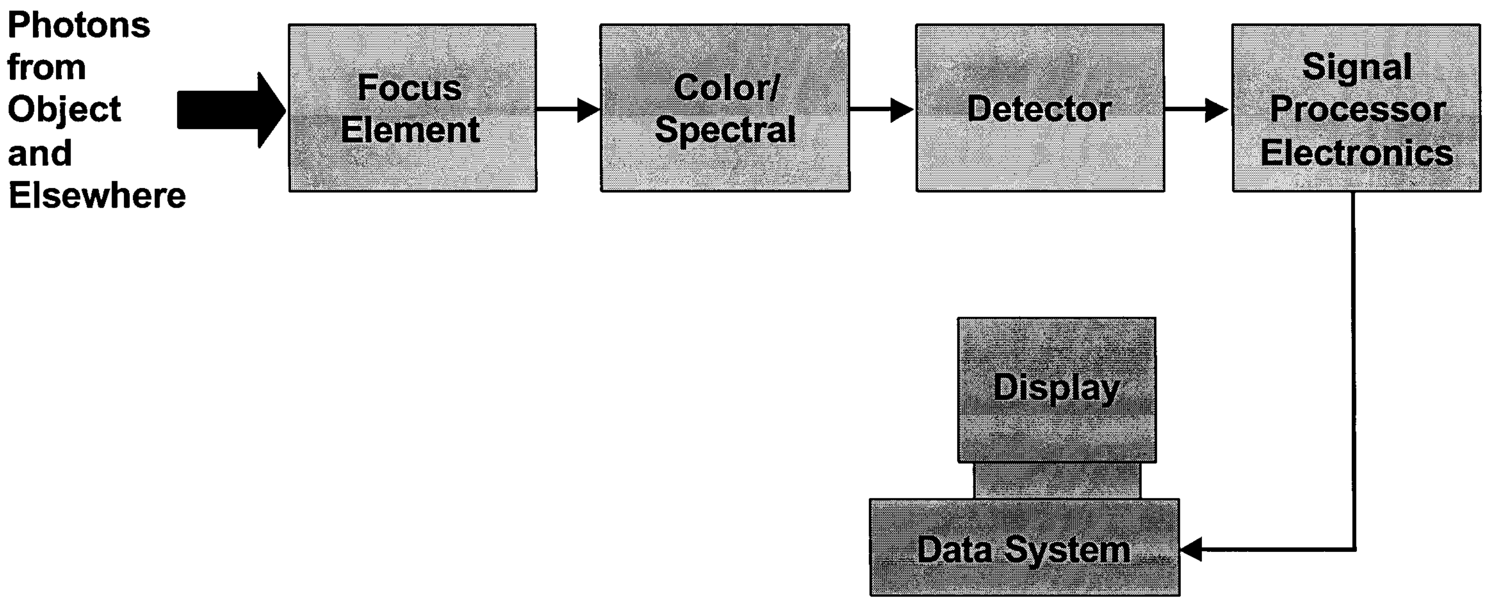


Idealized Planetary Occultation Experiment



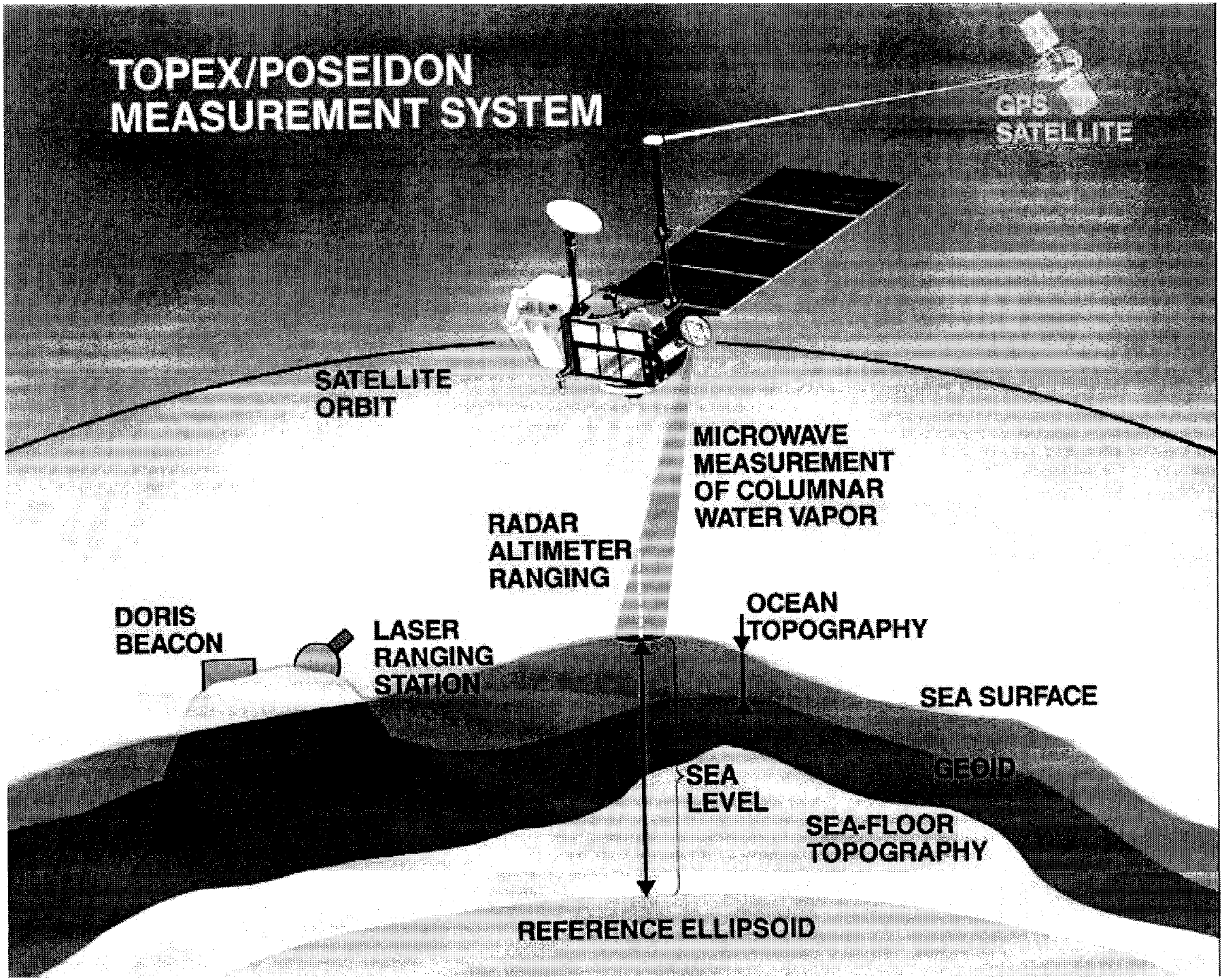
- Phase Change (doppler shift) due to refraction
- Amplitude reduction due to molecular absorption
- Changing transmitter/receiver separation
- Atmospheric diffraction and defocusing
- Local multipathing (reflections)
- Transmitter and receiver gain variations
- Absorption by other constituents

Generalized Instrument Block Diagram

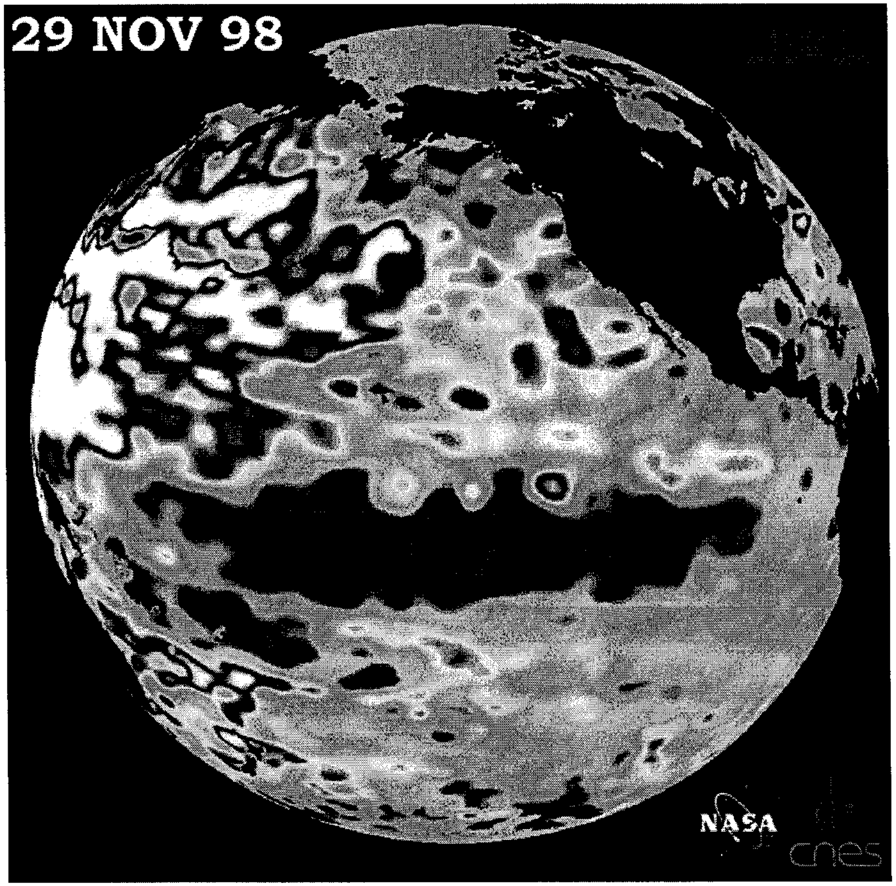


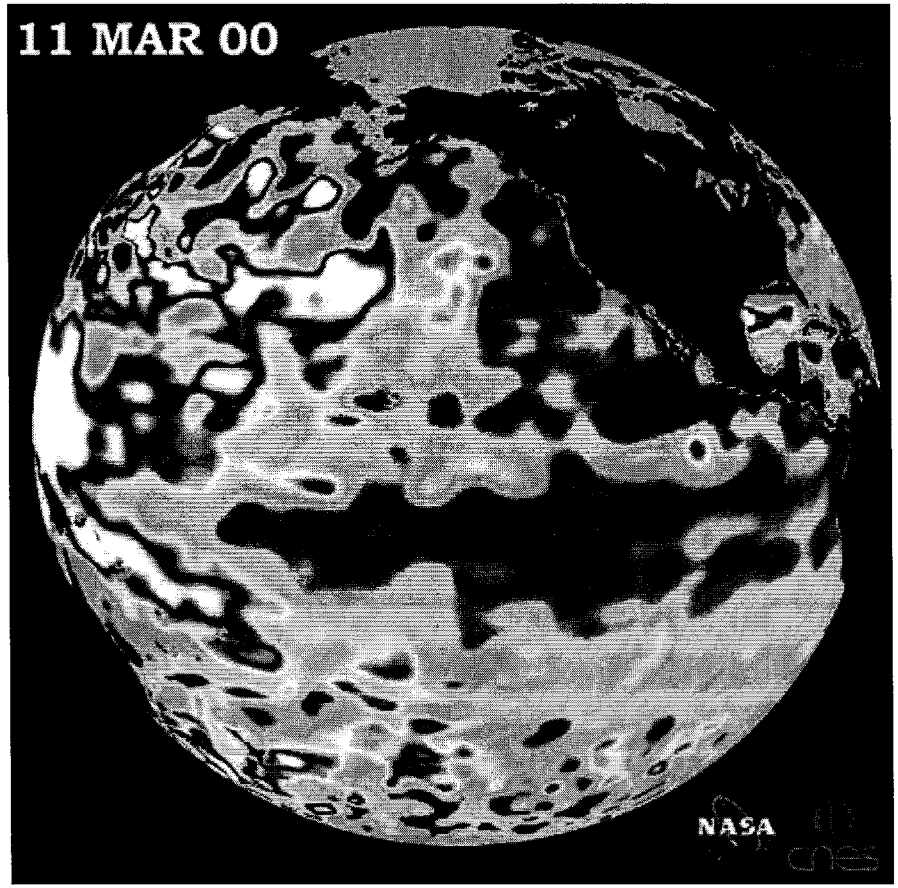
Why We Use Active Microwave Sensors

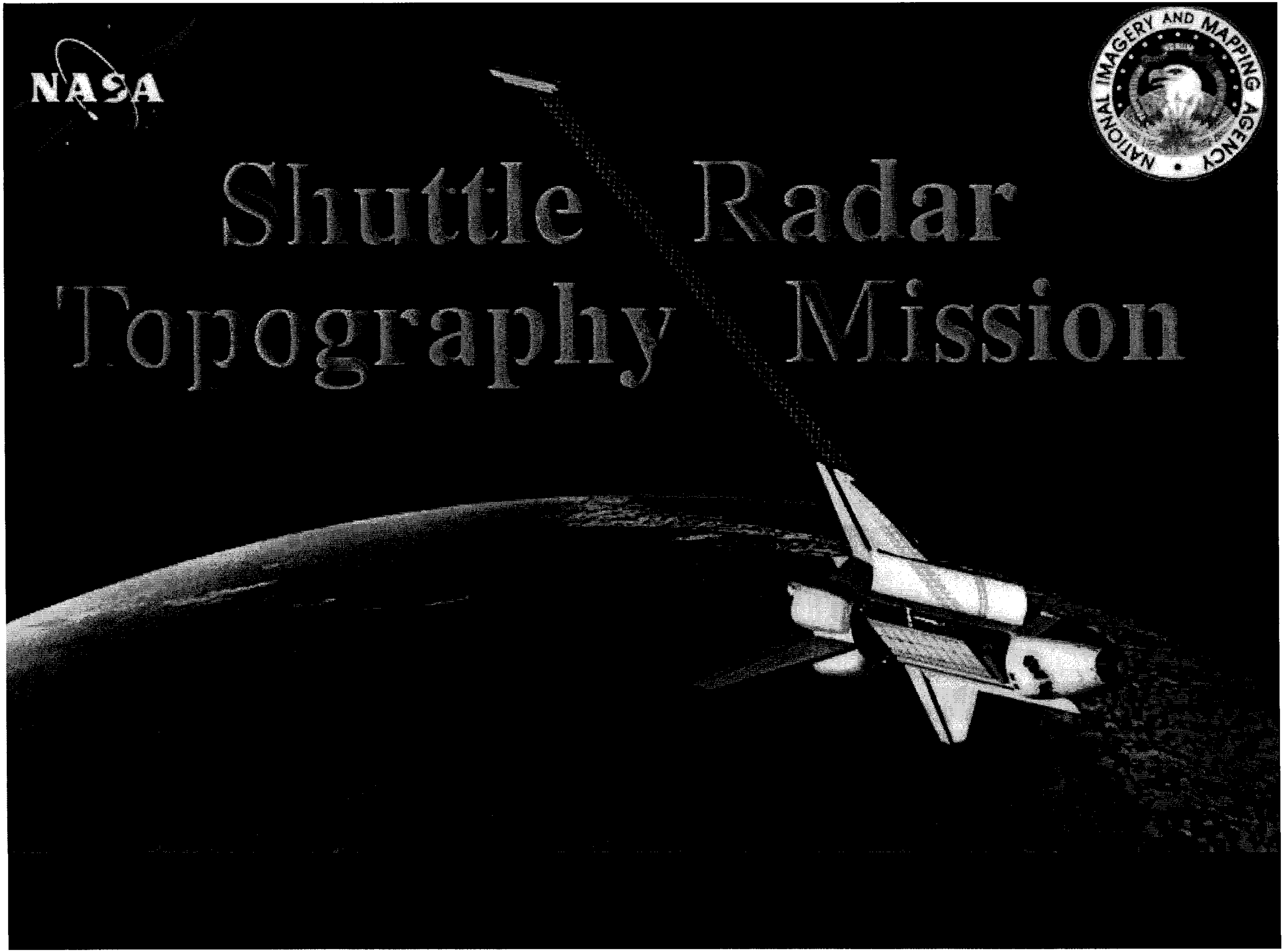
- Sensitivity to physical properties at scale of wavelength which is on same scale as many surface features
  - Topography
  - Morphology
  - Roughness
  - Discrete Scatterers
- Sensitivity to dielectric properties: eg. hydration, soil moisture
  - Hard targets
  - Moisture
  - Salinity
- All-weather, day-night observations
- Selectable geometry
- Long wavelength penetration capability
- Phase coherence allows interferometry at RF wavelengths


TOPEX/POSEIDON
MEASUREMENT SYSTEM
GPS
SATELLITE
SATELLITE
ORBIT
MICROWAVE
MEASUREMENT
OF COLUMNAR
WATER VAPOR
RADAR
ALTIMETER
RANGING
DORIS
BEACON
LASER
RANGING
STATION
OCEAN
TOPOGRAPHY
SEA SURFACE
GEOID
SEA
LEVEL
SEA-FLOOR
TOPOGRAPHY
REFERENCE ELLIPSOID

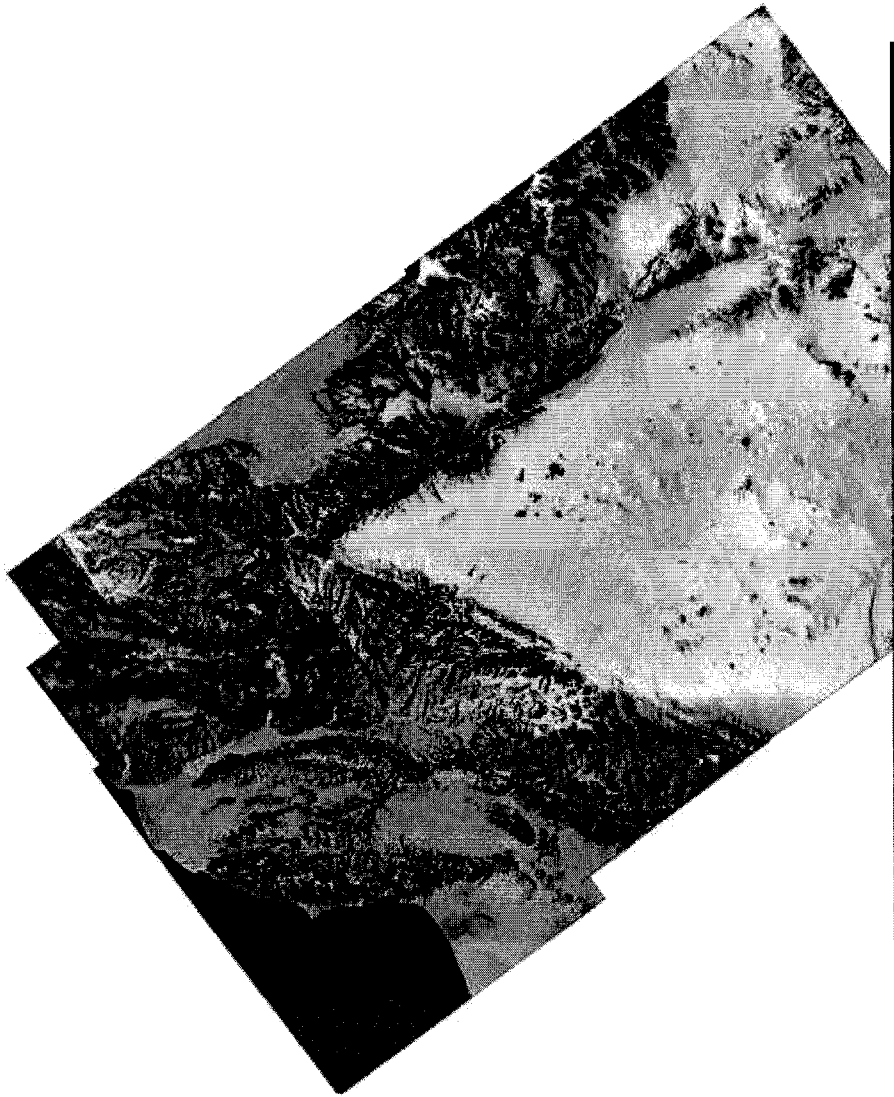
TOPEX La Niña

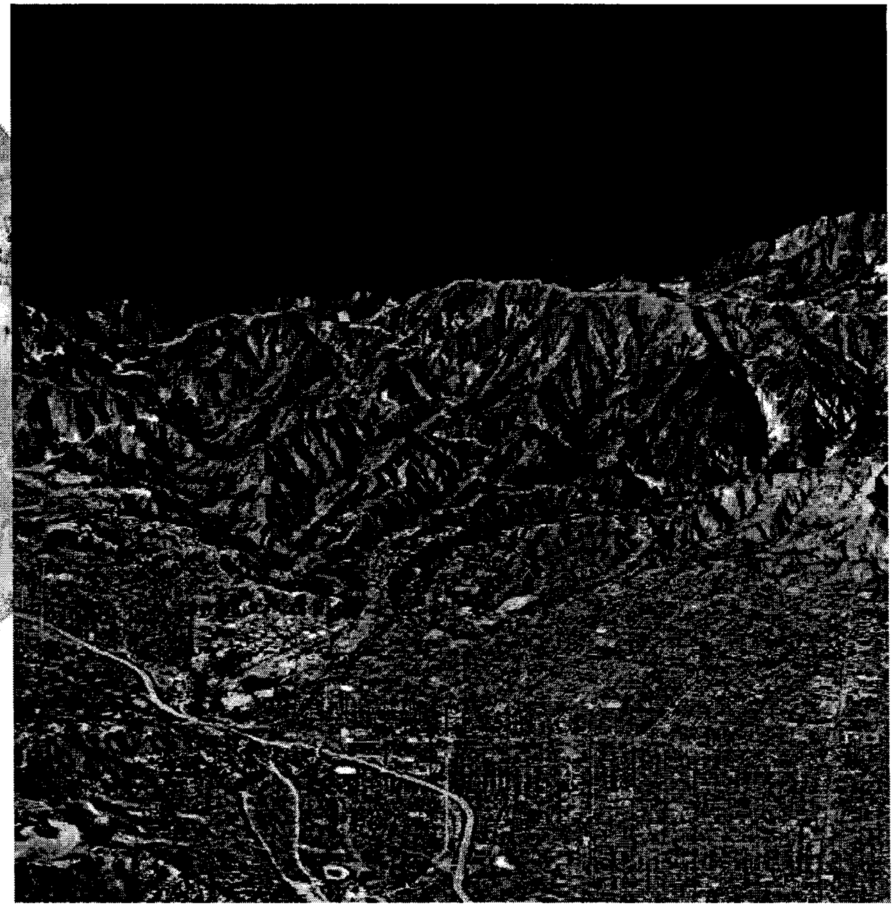





NASA
NATIONAL IMAGERY AND MAPPING AGENCY
Shuttle Radar
Topography Mission

SRTM Maps





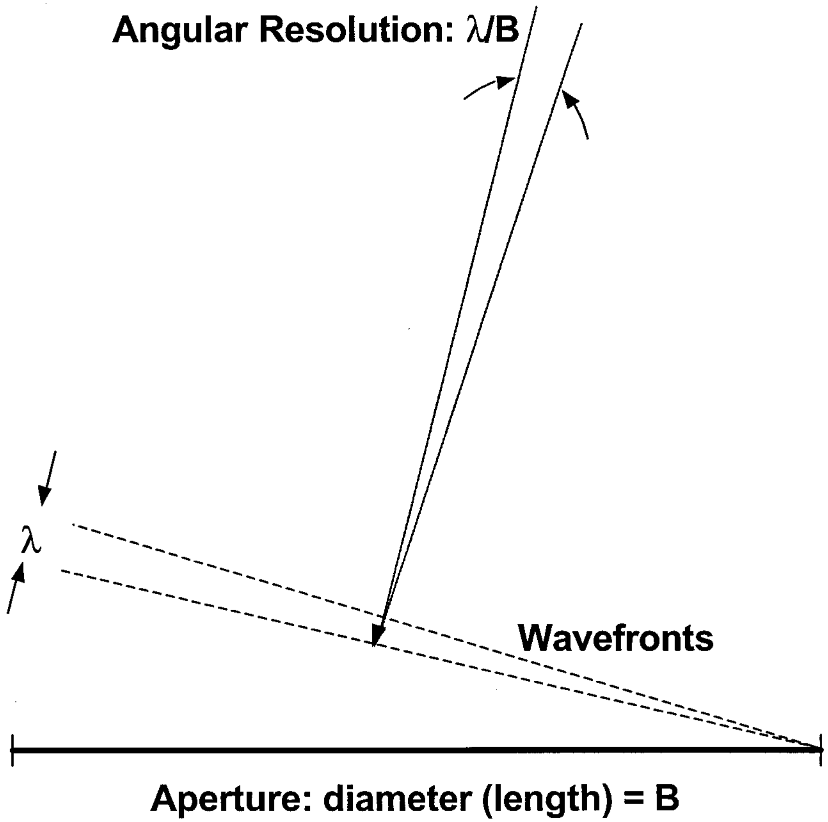
Type of Interferometers

(Fizeau vs. Michelson) pay per view

- "All imaging is an interferometric process" F. Roddier
- Dividing line between telescope and interferometer is not strict, but to first order
  - Fizeau interferometer forms a direct image
  - Michelson interferometer forms a synthetic image

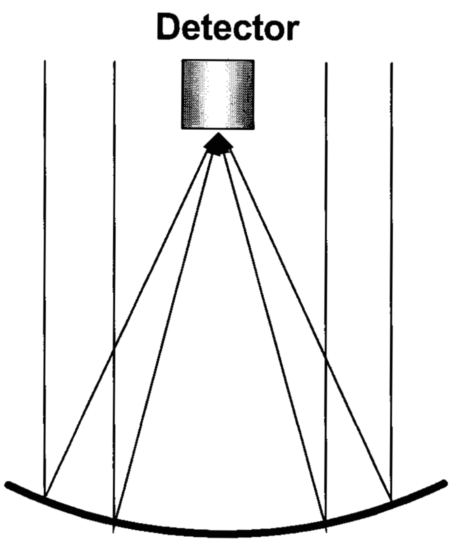
Angular Resolution

- Resolution is a function of
  - Wavelength of light: λ
  - Largest dimension of instrument: B
    - Telescope: diameter
    - Interferometer: separation of apertures
    - Diffraction limits angular resolution to ~λ / B

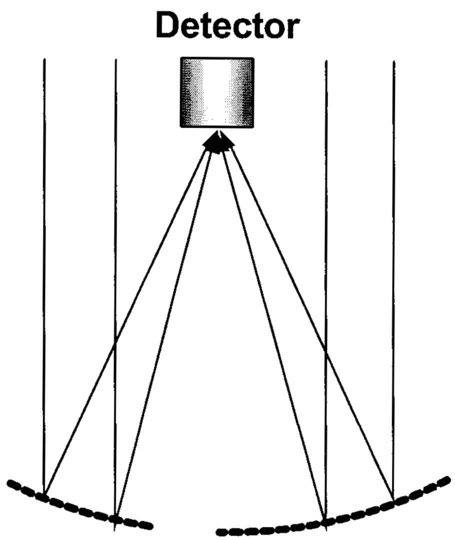


Fizeau Interferometers

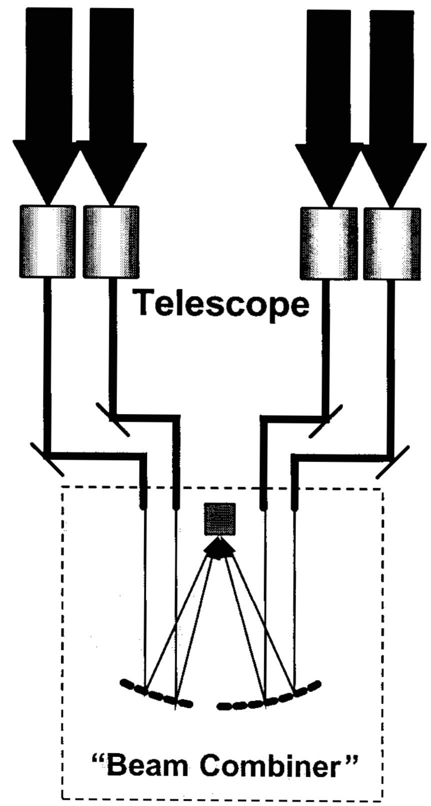
Telescope



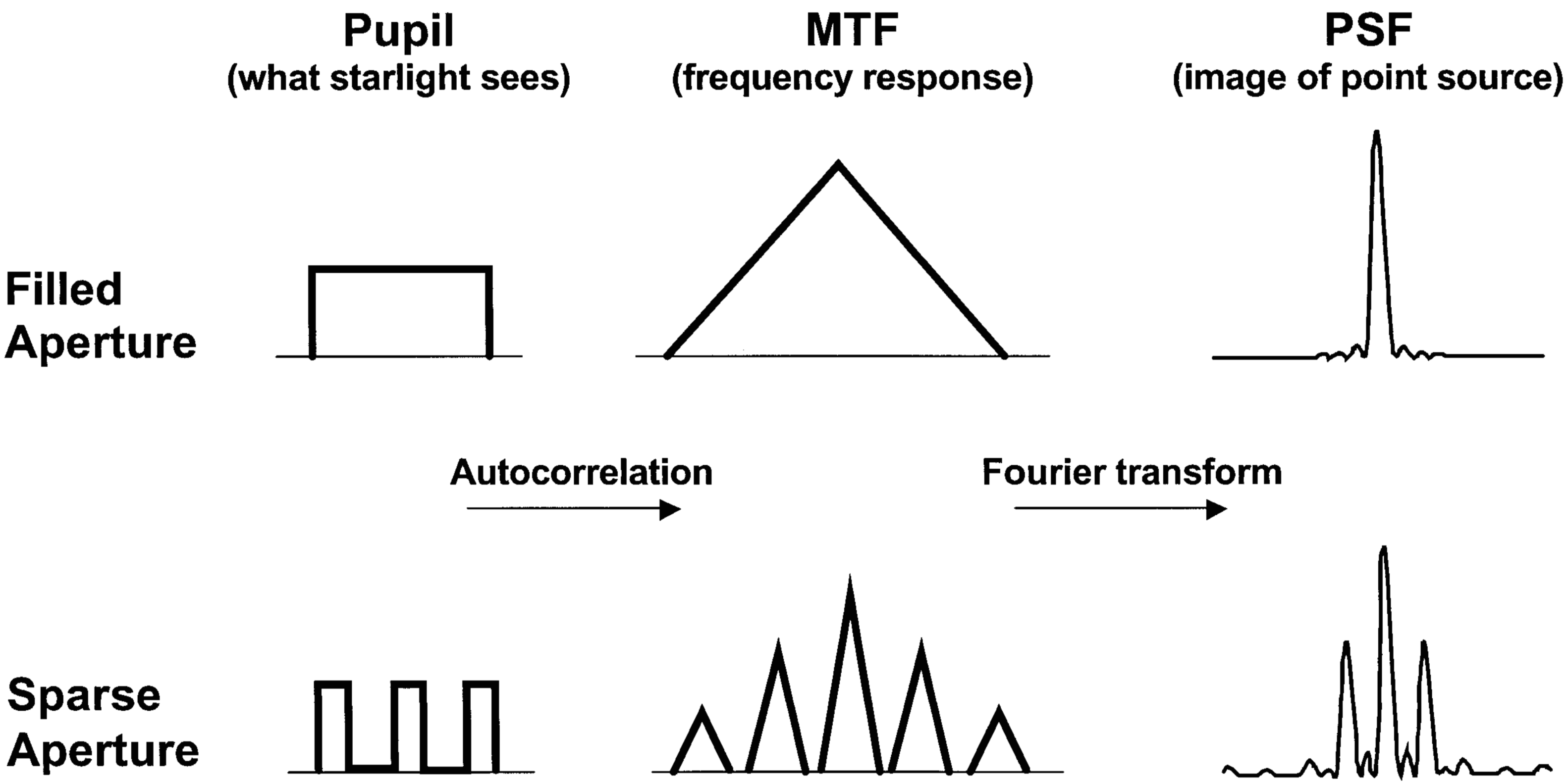
Sparse Aperture Telescope



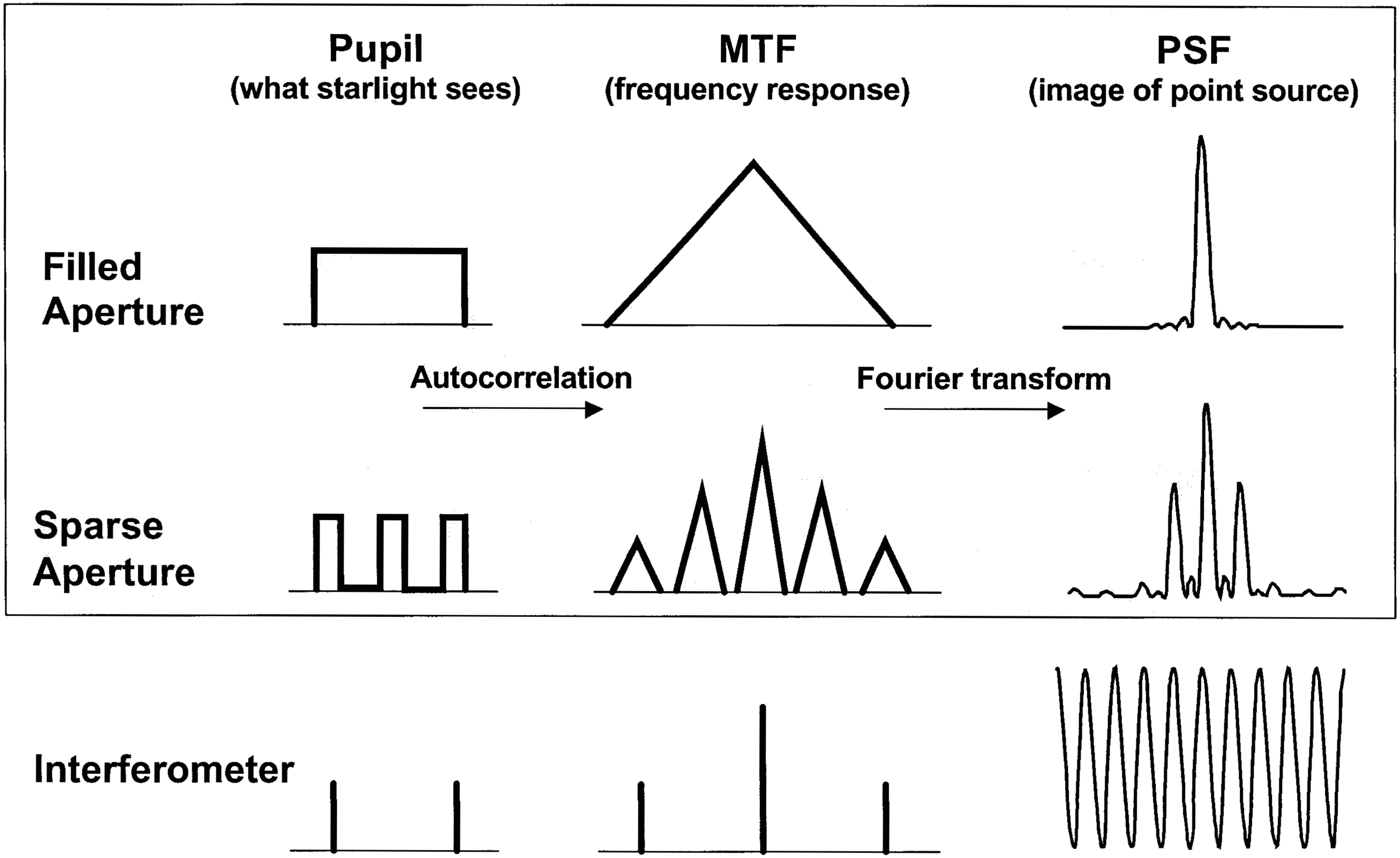
Fizeau Interferometer



PSFs for Sparse Apertures

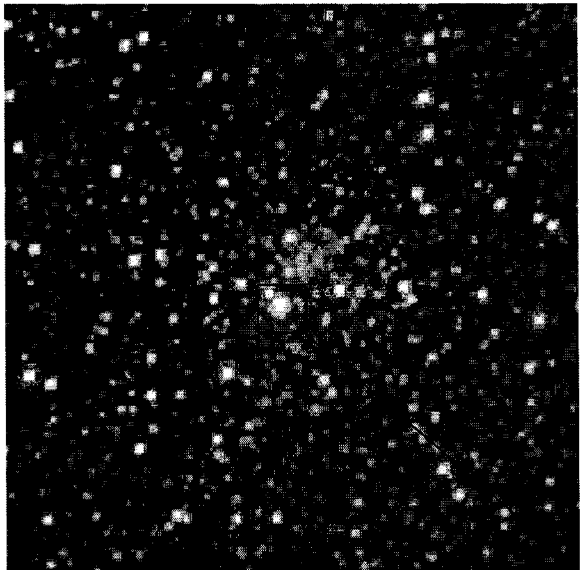


Another Way to Look at Fringes



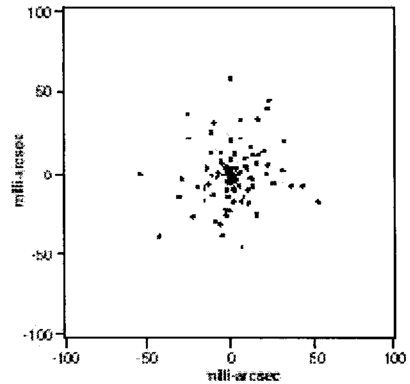
High Resolution Imaging

HST-WFPC2



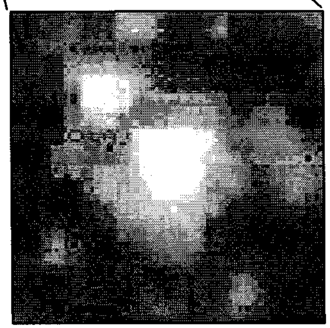
Over small fields of view SIM will show details that currently elude large telescopes. A simulated globular cluster core is used to illustrate this.

Cluster Core Model



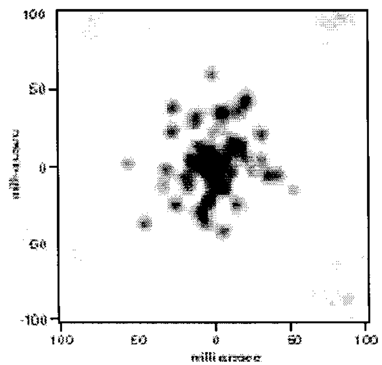
"true star positions"

Actual field of view larger than shown



Resolution (FWHM)
53 milliarcsec

SIM



Resolution (FWHM)
10 milliarcsec

Field of View
0.3 arcsec

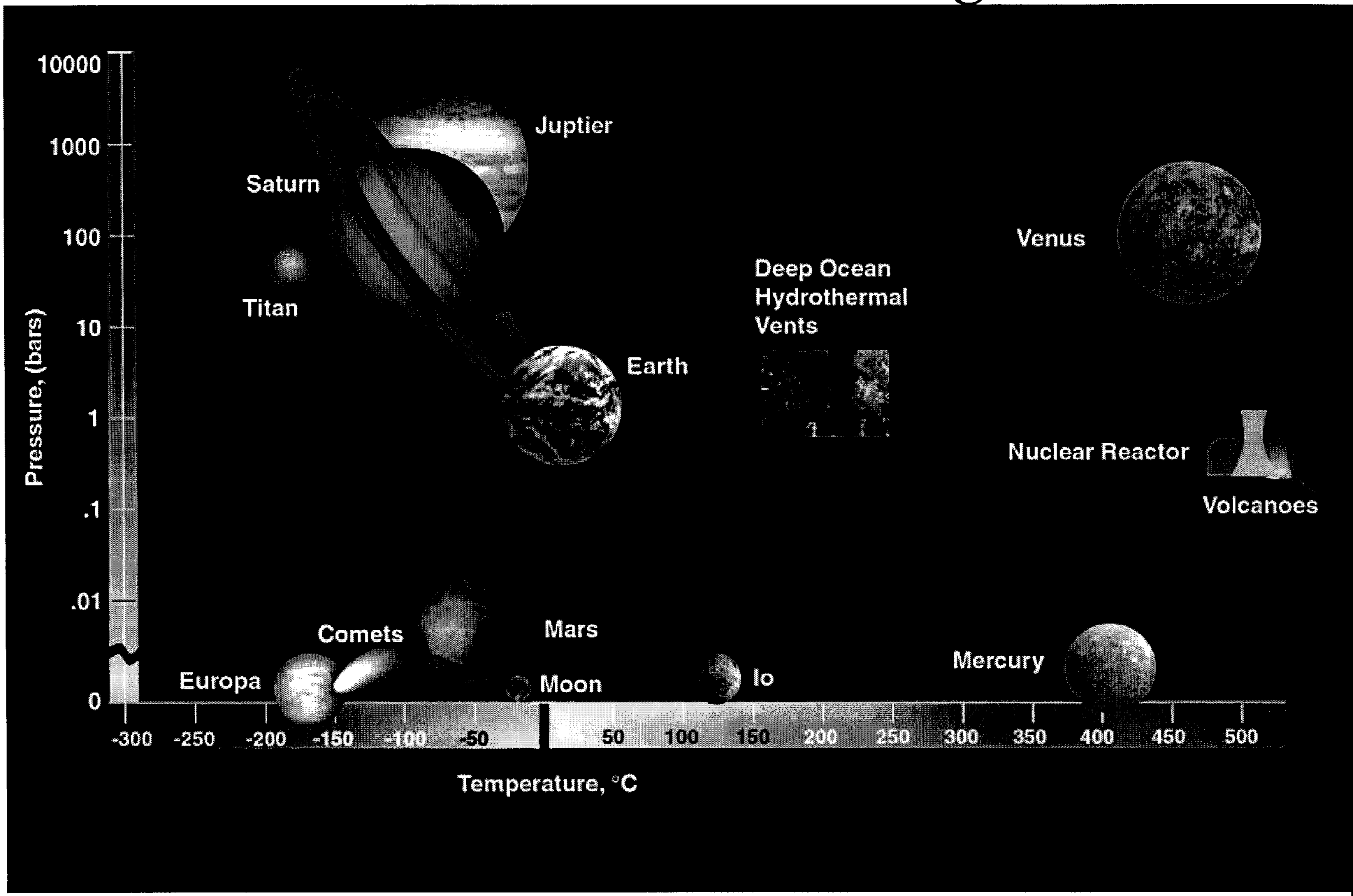
Summary

- The common thread is the measurement of photons and their characterization
- The physics of the process to be investigated needs to be understood by the instrument designer
- Quantitative improvements in accuracy tend to lead to qualitative improvements in understanding

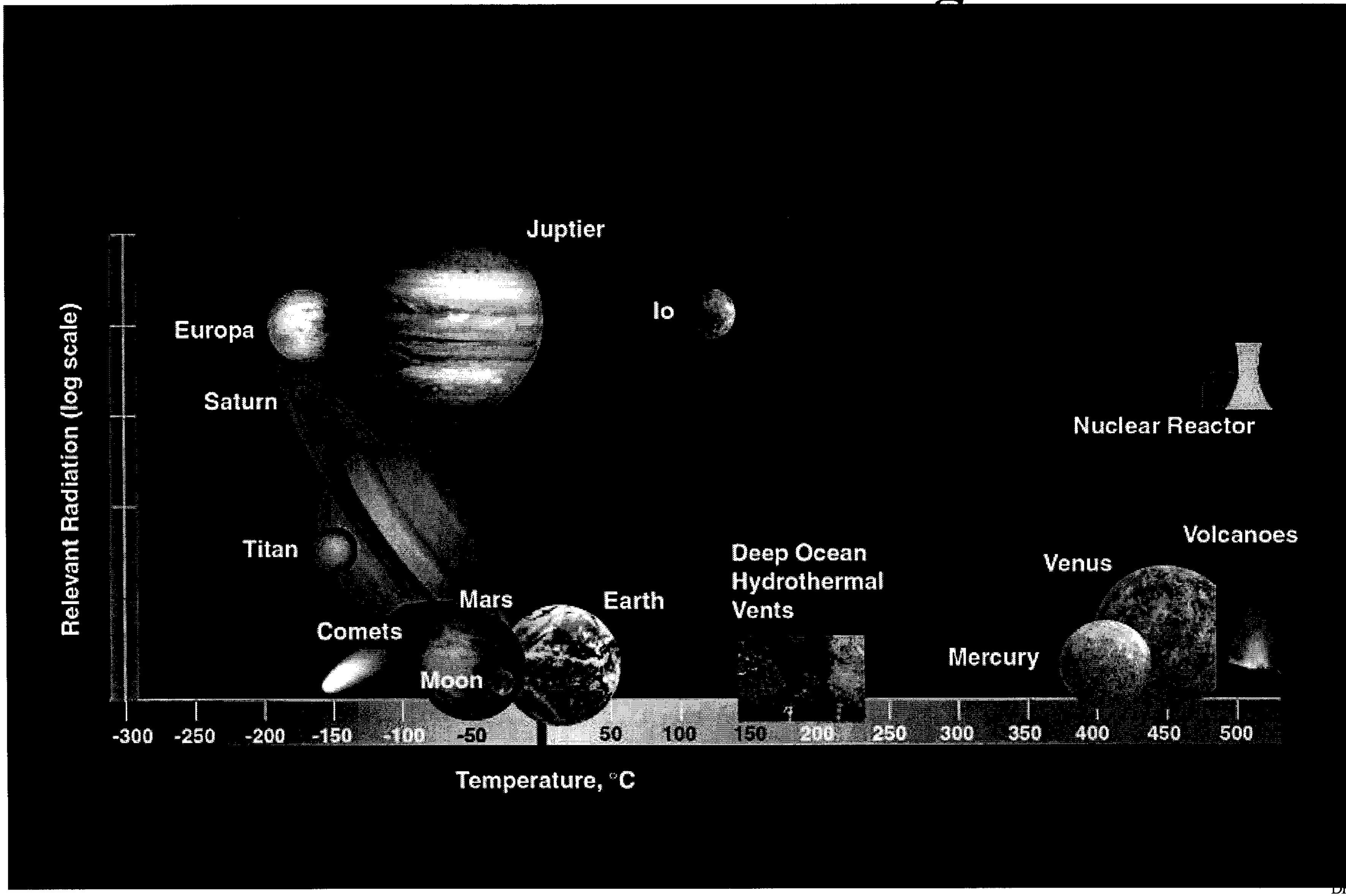
In-Situ Instrumentation
Definition and Comments

In situ measurements are those performed in close proximity (near, on, within) the object of interest. In solar system exploration, these measurements are often performed within hostile environments, when compared to those endured for deep-space remote sensing. The environments frequently drive the instrumentation into severe design constraints for adequate capability, longevity and overall performance

Environmental Challenges

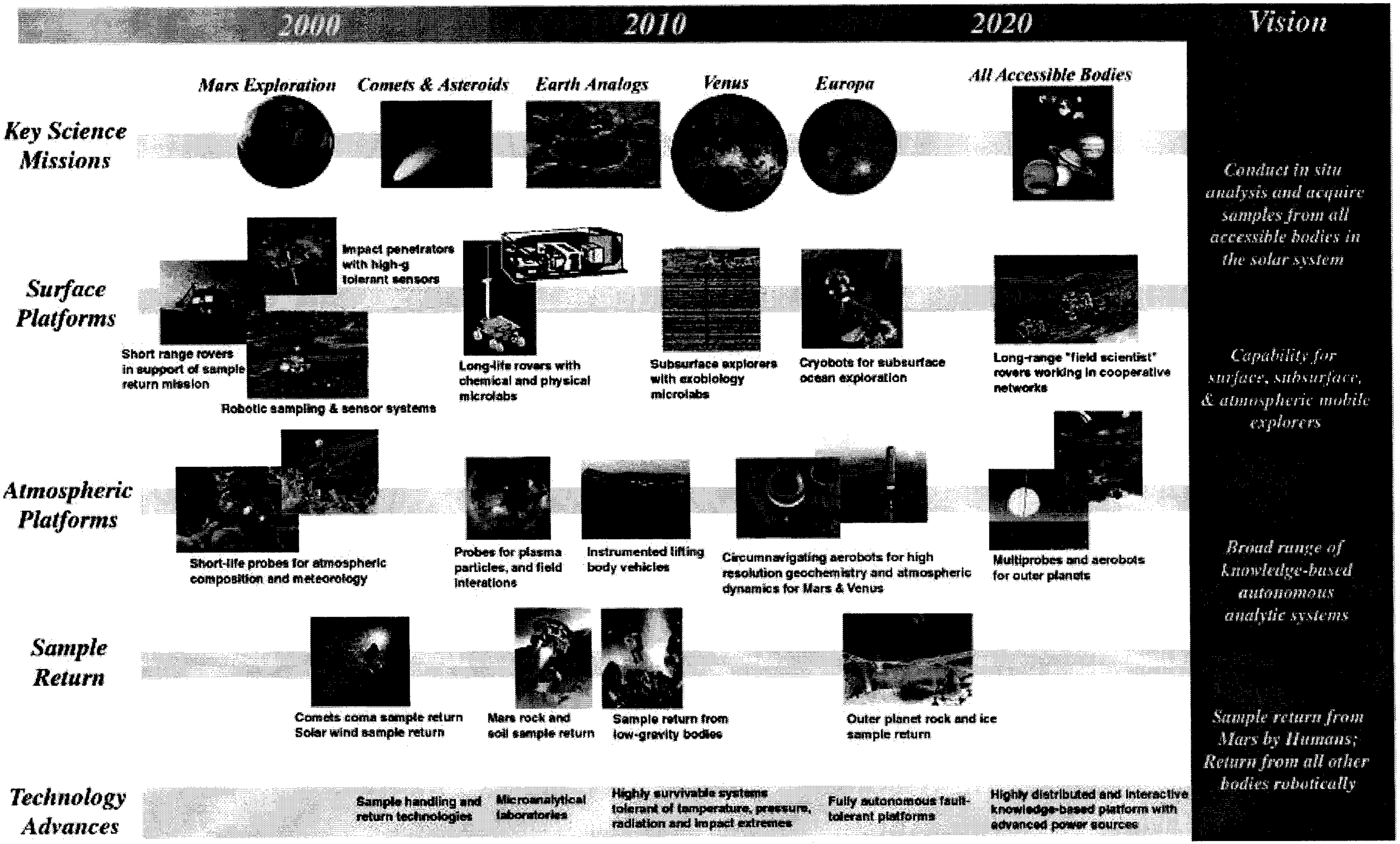


Environmental Challenges



Space Science Enterprise Workshop (SSE)

CISSR Roadmap



For updates, please contact William Hoffman at: william.hoffman@jpl.nasa.gov

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In-Situ Instrumentation
Instruments and Applications

• Nuclear Magnetic Resonance	Environment of protons in solids and liquids; detection of water, water ice, conversion of water and carbon into simple organics
• Electron Microscopy	Microscopic sample imaging, texture and elemental composition
• Tunable Laser Diode Spectroscopy	Minor constituent detection (vapor phase), isotope ratios, effluent detection
• Chemical Film Systems	Reactivity assessments, trace composition, specific species
• Gas Chromatography	Atmospheric gases, evolved gases, gaseous isotopes, organics, large molecules, horrendous mixtures
• Electrophoresis	Large molecules, peptides, proteins, inorganic salts, soluble minerals
• Mass Spectroscopy	Atmospheric gases, evolved gases, age dating with isotopes, organics, large molecules

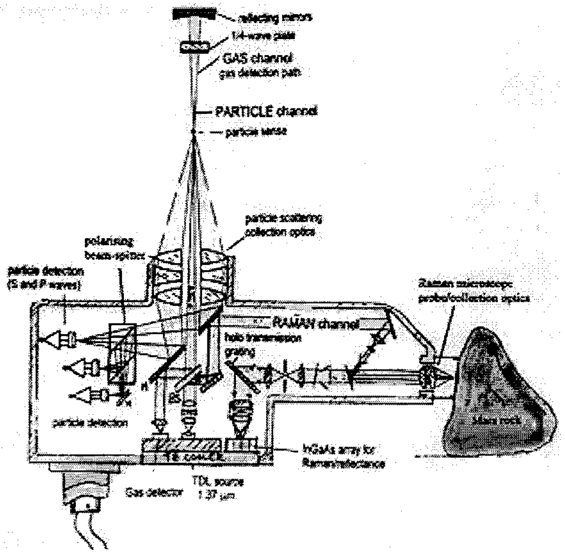
In-Situ Instrumentation

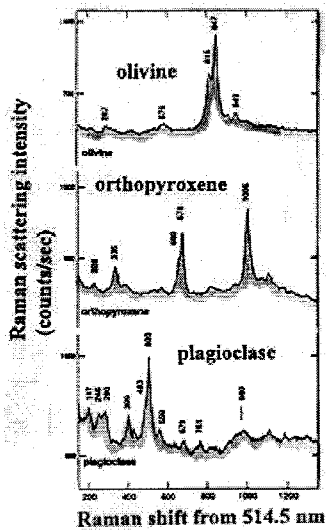
Instrumentation for Exobiology on Planetary Surfaces

(Currently Available)

To obtain:	An understanding of planetary environment	Identificati on of key sample	Key chemical or morphological measurement
Alpha-proton-x-ray	X	X	
"Aqueous chemistry"	X		
Gamma-ray spectroscopy	X		
Gas chromatography	X	X	X
Imaging	X	X	X
Infrared spectroscopy	X	X	X
Mass spectrometry (isotopes)	X	X	X
Mass spectrometry (organics)	X	X	X
Mössbauer	X	X	X
Neutron activity	X		
Neutron spectroscopy	X		
Raman spectroscopy	X	X	
Scanning electron microscopy		X	X
Secondary ion mass spectrometry		X	X
Thermal analysis	X	X	X
X-ray diffraction/fluorescence	X	X	X

Combination Laser Absorption and Raman IR Spectrometer (CLARIS)





Scientific Goals of Instrument

1 Determination of atmospheric gas composition (e.g. H_2O, CO_2 and isotopes)

1 Determination of mineralogical composition for rocks and soil on Martian surface

1 Determination of atmospheric particle size distributions and number densities

Measurements Made by Instrument

1 Concentrations of selected gases using near-IR laser absorption spectroscopy

1 Near-IR laser Raman spectroscopy detection at 1-2 microns

1 Particle size distributions and numbers densities from laser particle spectrometry

1 High resolution (0.0001 cm-1) near IR; < 2% measurement precision required

Instrument Description

1 Single room-temperature tunable diode laser at 1.3 microns with detection in 1.3-2.3 microns using AlGaAs arrays

1 Miniature laser spectrometer with capability for simultaneous measurement of gas, mineral and particle abundance's

Development Status

1 Gas concentration channel is similar to MVACS TDL spectrometer

1 The laser Raman channel is completely new and untested even in laboratory

Ready for Flight Development? 9 now 9 '03 '05 ! >'07

Possible Vehicles (rover (lander 9 mole/penetrator 9 aerobot 9 glider 9 other ________

Profile Mass: 1 Kg Power: few W Volume: < 2 liters

Dependencies on other Instruments Developments?

Who/Funding

1 Chris Webster (PI) 1 DRDF, PIDDP

1 JPL, Caltech

Microfabricated Capillary Electrophoresis for the Chiral Analysis of Amino Acids

Perform CE analysis

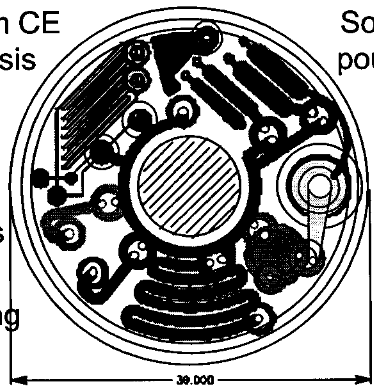
Solution pouches

Add chiral separators

Add soln to soil & heat

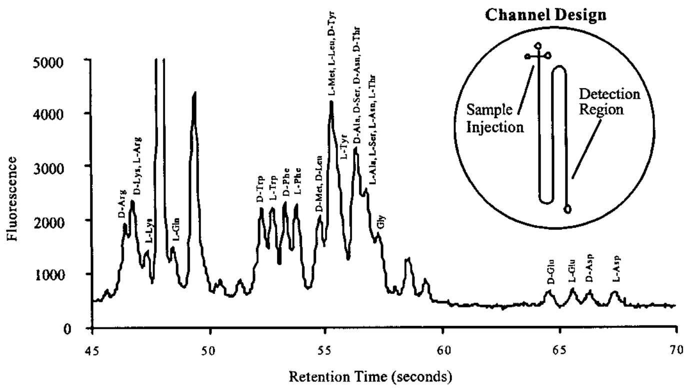
Add labeling reagents

Desalt solution



Concentrate solution

Diagram of integrated sample handling and microfluidics



Data demonstrating enantiomeric resolution of amino acid standards using a microfabricated CE with LIF detection

Scientific Goals of Instrument

1 **Search for evidence of past or extant life on Mars**

1 **Determination of biotic vs. abiotic origin of amino acids extracted from soil/rock**

Measurements Made by Instrument

1 **Detects amino acids extracted from Martian rock/soil with femtomolar sensitivity**

1 **Uses calibration solutions to identify which amino acids are present**

1 **Resolves D- and L-enantiomers for each detected amino acid**

Instrument Description

1 **Performs wet-chemistry extraction of organics from soil/rock using emerging microfluidic technologies**

1 **Isolates and fluorescently tags amino acids**

1 **Analyzes amino acid abundances using microfabricated capillary electrophoresis (CE) with laser-induced fluorescence (LIF) detection**

1 **Addition of cyclodextrin inclusion complexes provides for chiral resolution**

Development Status

1 **Demonstrated enantiomeric resolution of standard amino acid solution using microfabricated CE/LIF (see spectrum)**

1 **Extraction of amino acids using microfluidics now under development**

Possible Vehicles (rover (lander (mole/penetrator 9 aerobot 9 glider 9 other

Ready for Flight Development? 9 now **('03** 9 **'05** 9 **>'07**

Dependencies on other Instrument Developments?

Profile Mass: 500 g Power: <1 W Volume: 0.5 liter

1 no

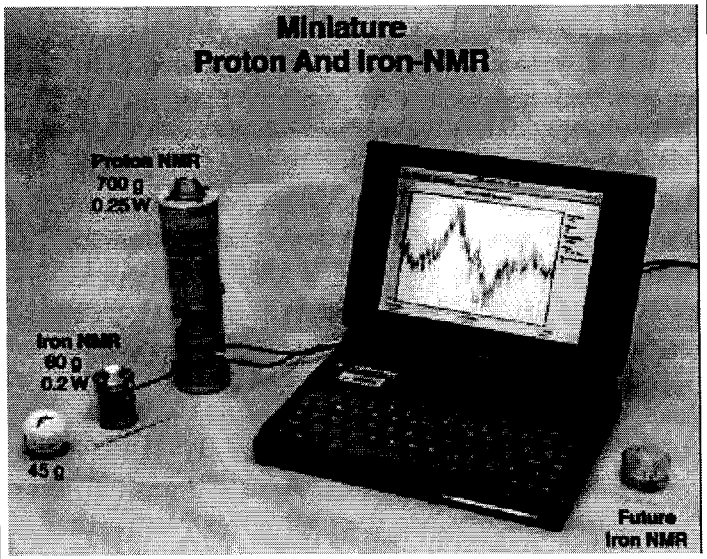
Who/Funding

1 Jeff Bada (PI)

1 Scripps UCSD, UC Berkeley, JPL

1 NASA Sensor program, PIDDP

Miniature Proton-Nuclear Magnetic Resonance (NMR) Spectrometer



Scientific Goals of Instrument

1 Detection and quantity of various forms of water (adsorbed, chemically bound) in soil, rock samples

Measurements Made by Instrument

1 Quantitative measurements of water contents in soil, mineral samples

1 Sensitivity 0.1 wt%

Instrument Description

1 Detection of protons through interaction of proton nuclear spins with molecular and magnetic field environment

1 Consists of a permanent magnet, radio frequency coil, pulsed or continuous wave NMR circuit, digital signal processing circuit

1 Sample Size: 1-2 cc

Development Status

1 Will be field tested in Sahara Desert and Antarctica in Nov/Dec, 1998 by Chris McKay

Ready for Flight Development? 9 now ('03 ('05 (>'07

Profile Mass: 800 gm Power: 0.25 W Volume: 600 cm^3

Possible Vehicles (rover (lander (mole/penetrator
9 aerobot 9 glider 9 other ________

Dependencies on other Instruments Developments?

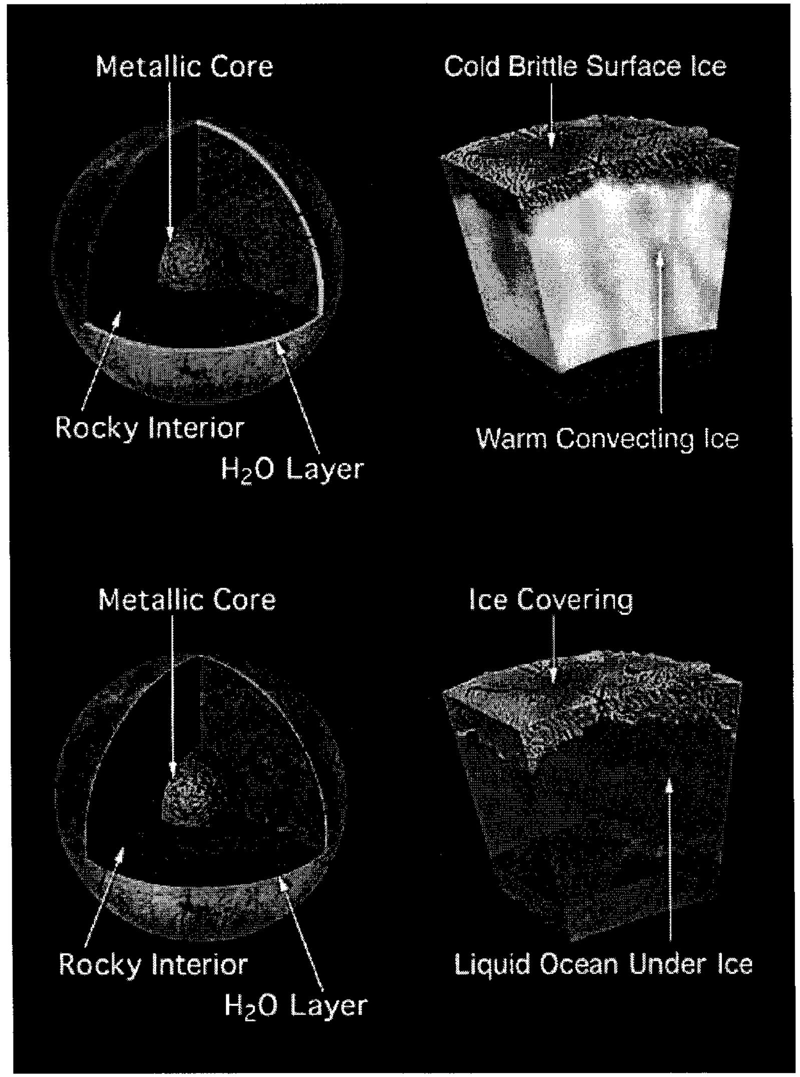
1 None

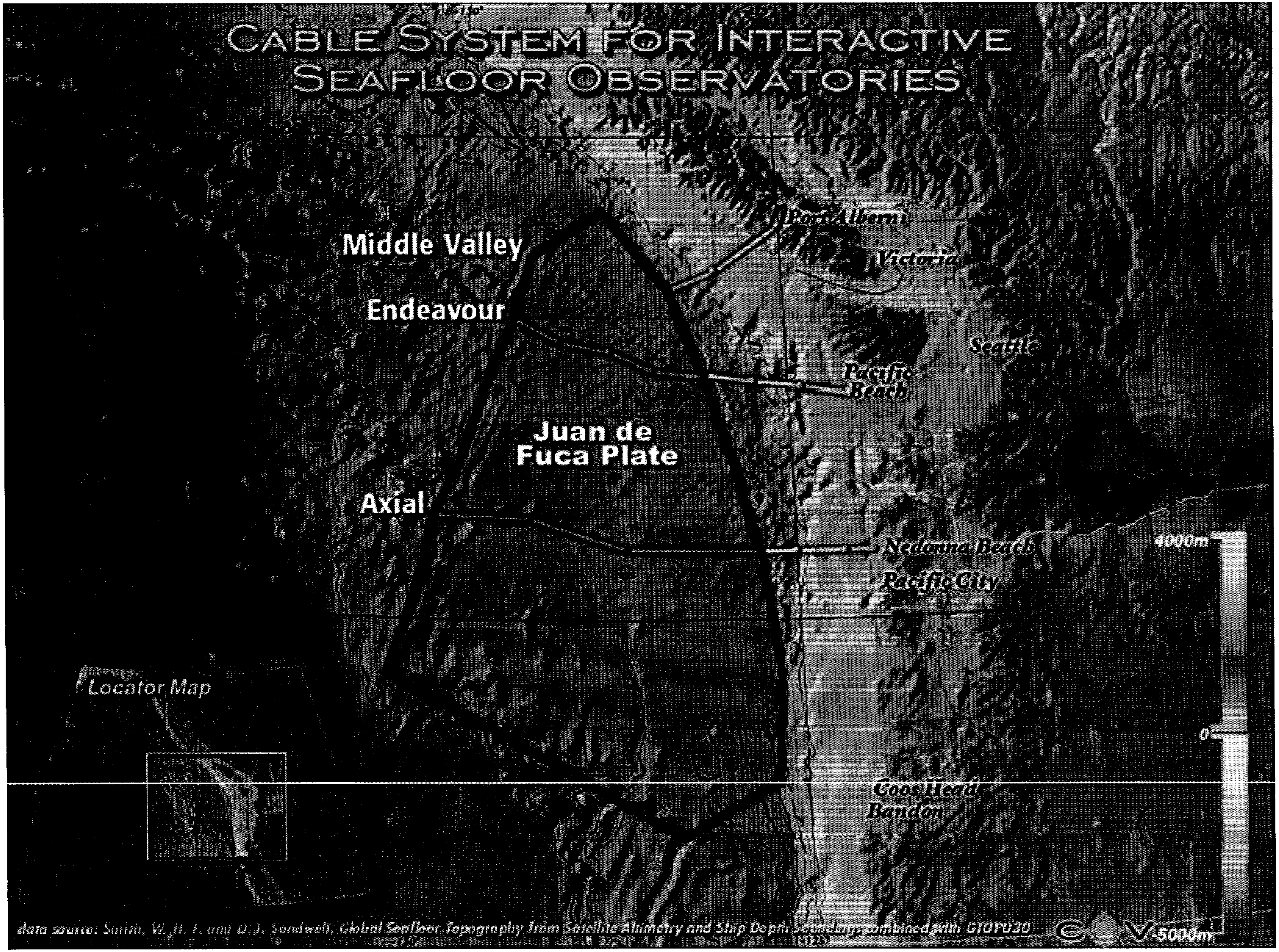
Who/Funding

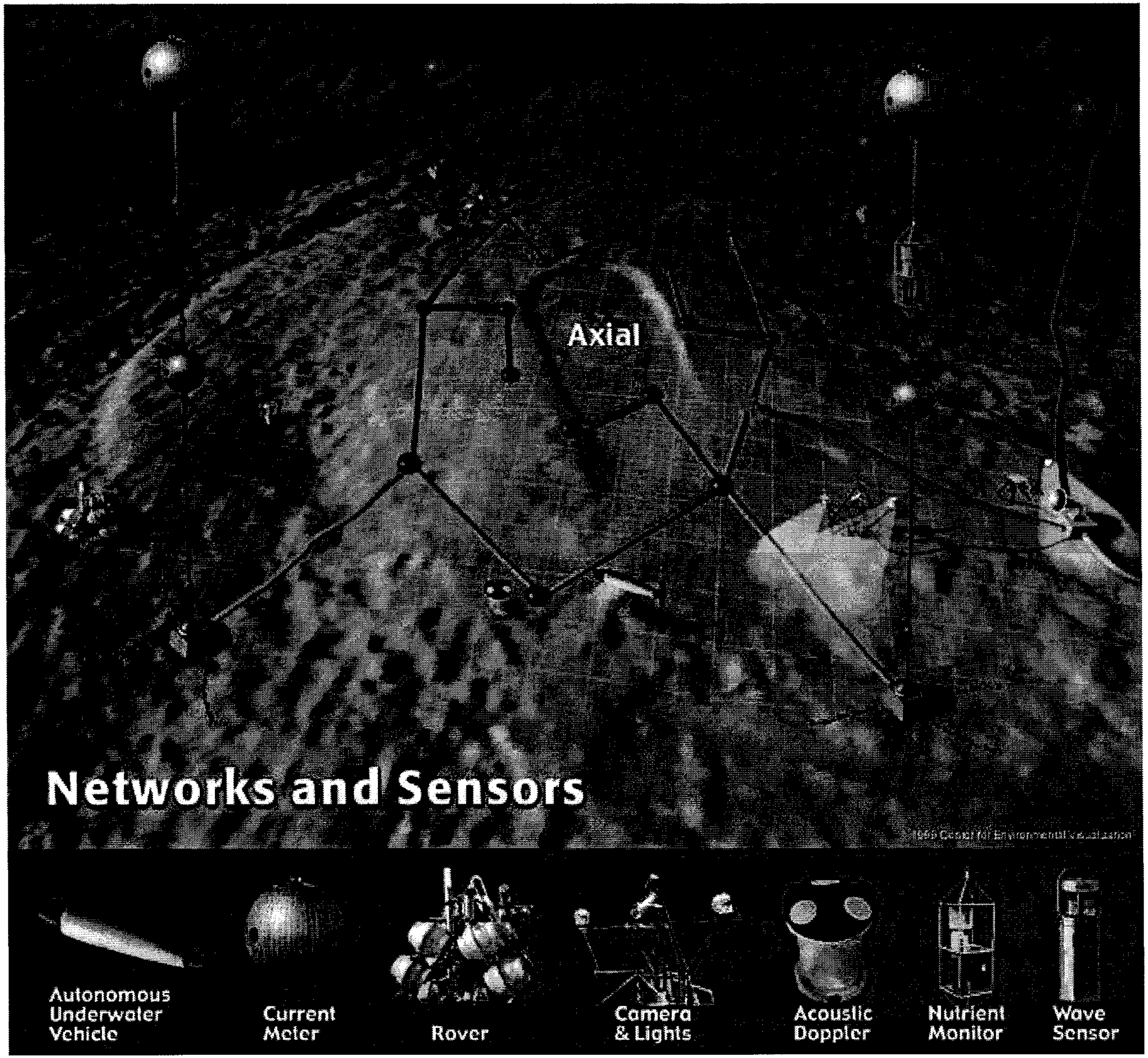
1 Soon Sam Kim (PI) 1 PIDDP

1 JPL

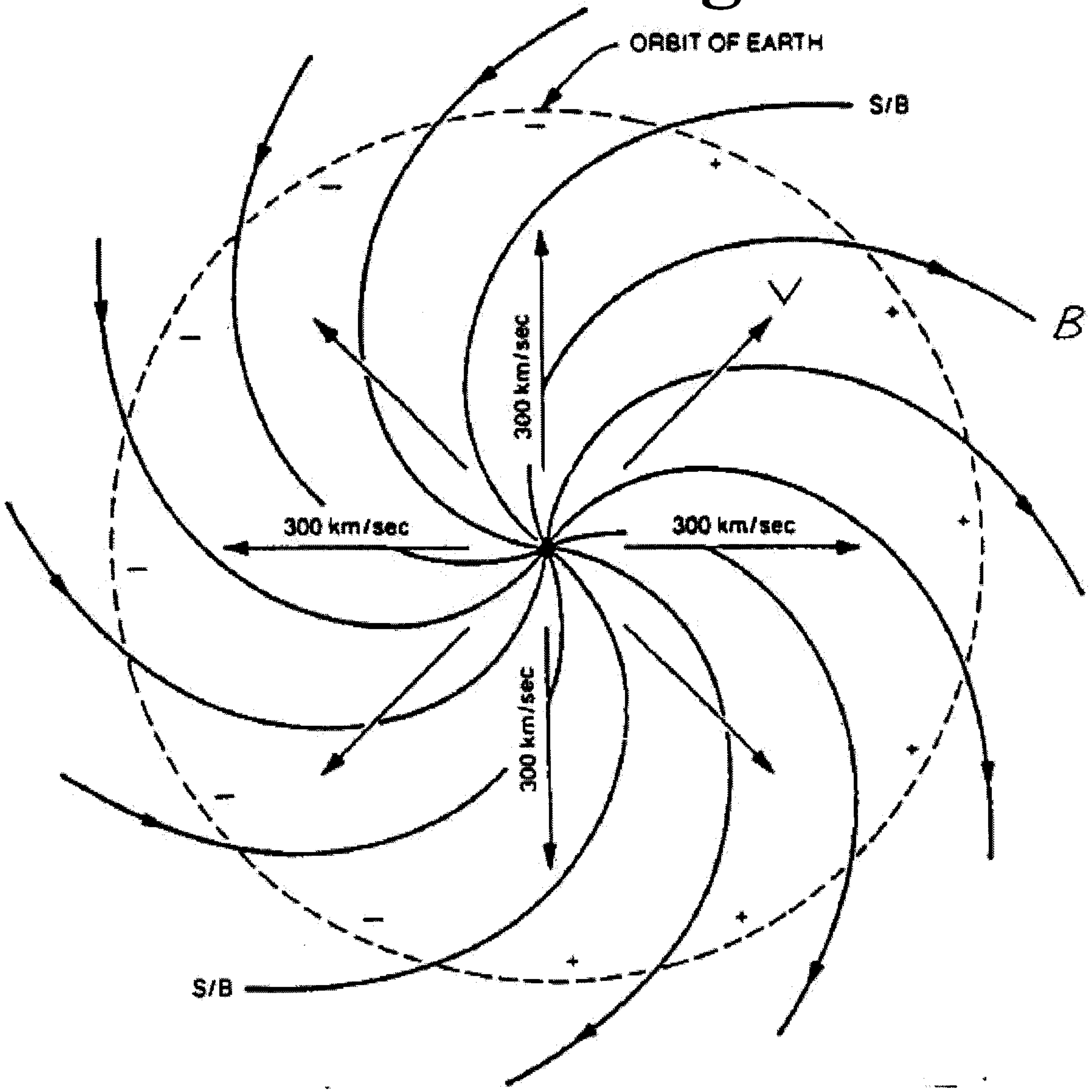
Europa

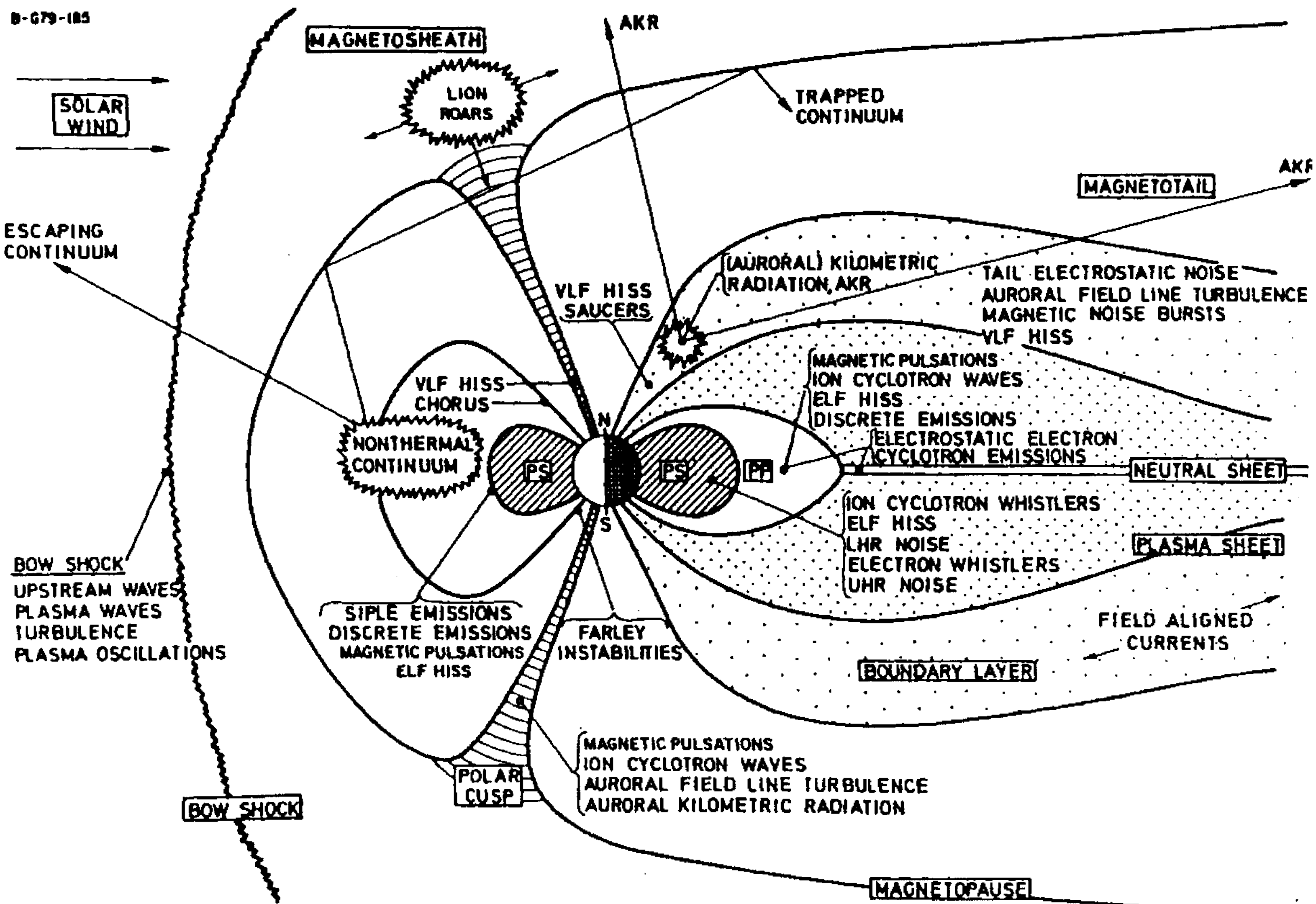

Metallic Core
Cold Brittle Surface Ice
Rocky Interior
H_2O Layer
Warm Convecting Ice
Metallic Core
Ice Covering
Rocky Interior
H_2O Layer
Liquid Ocean Under Ice


Cable System for Interactive
Seafloor Observatories
Port Alberni
Middle Valley
Victoria
Endeavour
Seattle
Pacific
Beach
Juan de
Fuca Plate
Axial
Nedonna Beach
Pacific City
4000m
0
Locator Map
Coos Head
Bandon
data source: Smith, W. H. F. and D. T. Sandwell, Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings combined with GTOPO30
-5000m


Axial
Networks and Sensors
Autonomous Underwater Vehicle
Current Meter
Rover
Camera & Lights
Acoustic Doppler
Nutrient Monitor
Wave Sensor

Solar Wind and Magnetic Field





PS = PLASMASPHERE PP = PLASMAPAUSE

Experiment Development

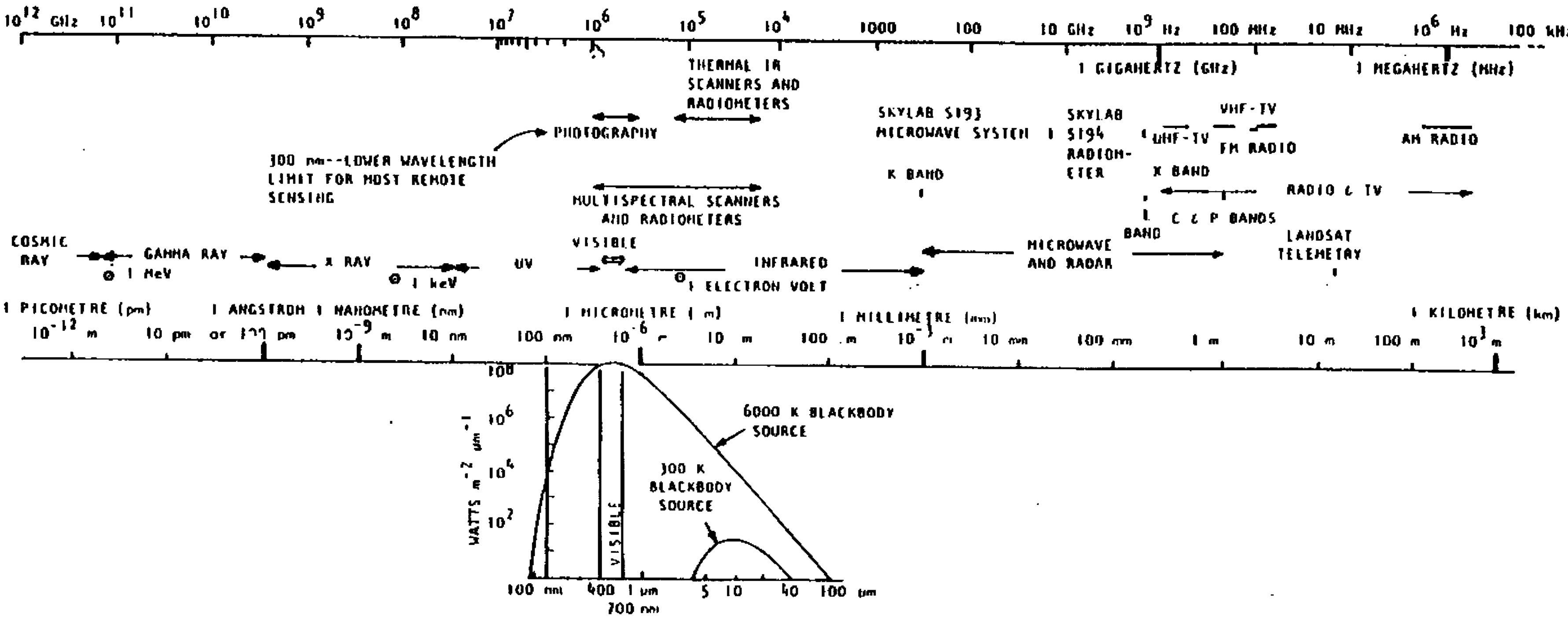
- Phases of an experiments evolution
- Science/User need ID
- Science ⇔ Engineering Interactions
- "The Proposal"
- Winning the Job
- Starting the Job - staffing/facilities/dollars/ teaming partners/interfaces/contracts/ ...

Experiment Development

- Implementation
- Delivery
- Integration Support
- “the Launch”
- Data Return
- Data Analysis/Reduction
- Science/User Results/Output

Imaging, Spectrometry & Radiometry

Electromagnetic Spectrum



The Many Energies of Light

X-rays and gamma rays span many decades in energy as "messengers" from different scale sizes and physical processes

Here are some typical x-rays and gamma-ray energies and the corresponding frequencies, wavelengths and associated scales sizes

Energy	Frequency	Wavelength	Scale Size
1 KeV	2.4×10^{17} Hz	1.2 nm	Atom
1 MeV	2.4×10^{20} Hz	1.2×10^{-12} m	Nucleus
1 GeV	2.4×10^{23} Hz	1.2×10^{-15} m	Nucleon
1 TeV	2.4×10^{26} Hz	1.2×10^{-18} m	Lepton

When characterizing the energy of x-rays or gamma rays, units of electron volts (eV) are typically used (1 eV = 1.602×10^{-19} J)

Blackbody -Planck's Radiation Formula

Planck's idea of quantizing radiation led him successfully to the mathematical description of the spectral distribution of radiation emitted from a perfect radiator or blackbody. Planck's blackbody law can be expressed as

$$M_\lambda = \frac{2\pi hc^2}{\lambda^5\left[\exp(ch/\lambda kT) - 1\right]}$$

Where the *spectral radiant exitance* M_λ is in W m^{-2} μm^{-1} if the quantities in Eq. (3.7) are given in the following units:

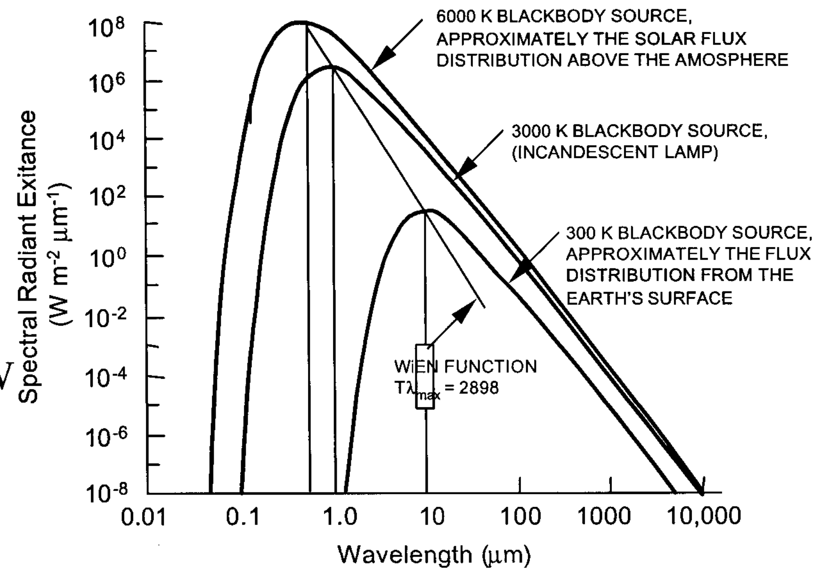
h = Planck's constant = 6.6256 x 10^{-34} W s^2,

c = velocity of light = 2.997925 x 10^8 m s^{-1},

k = Boltzmann's constant = 1.38054 x 10^{-23} W s K^{-1},

T = absolute temperature in degrees (K),

λ = wavelength in metres.



Imaging, Spectrometry & Radiometry

Geometric Illustration of Radiometric Terms

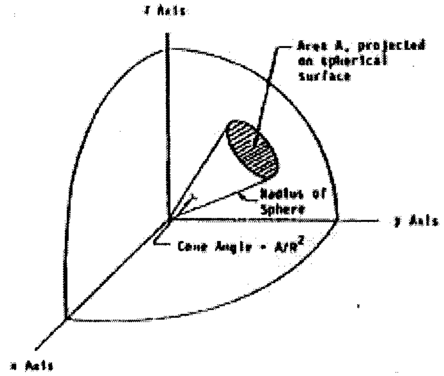


Fig. 2-8. The concept of the solid angle in angular measurement.

$$\Omega = \frac{a}{r^2}$$ Solid Angle in sterradians

$$\Omega = 4\pi \sin^2\left(\frac{1}{2}\theta_{1/2}\right)$$

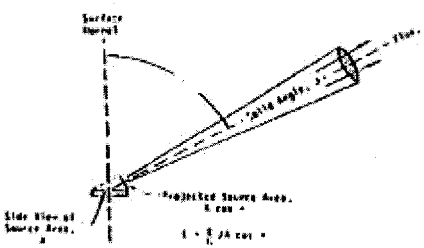


Fig. 2-10. The concept of radiance.

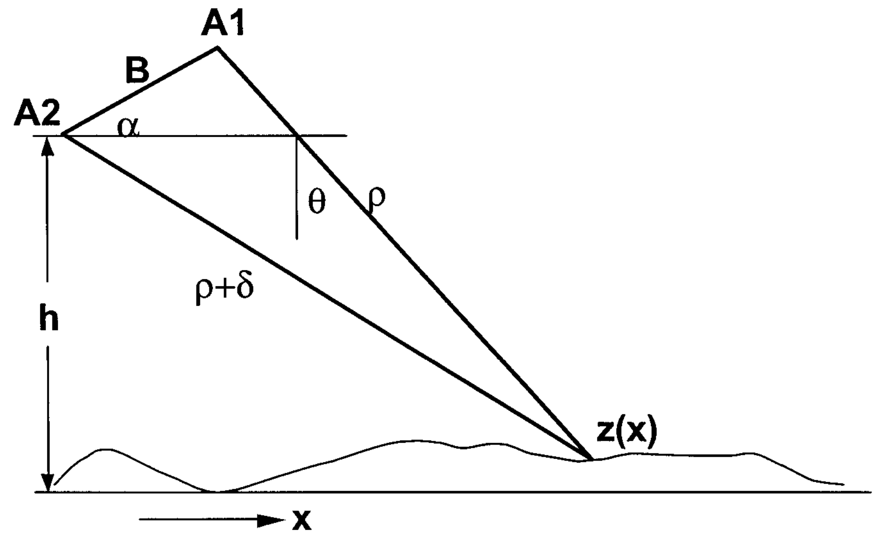
$$dA_{proj} = dA\cos\theta$$

$$L = \frac{d^2\Phi}{dA_{proj}\,d\Omega}$$

Radar Interferometry
Theory of Spatial Baseline Configurations

Defining geometry and parameters:

Surface topography	$z(x)$
Aircraft altitude	h
Baseline distance	B
Slant range	ρ
Look angle	θ
Baseline angle	α
Path length difference	δ



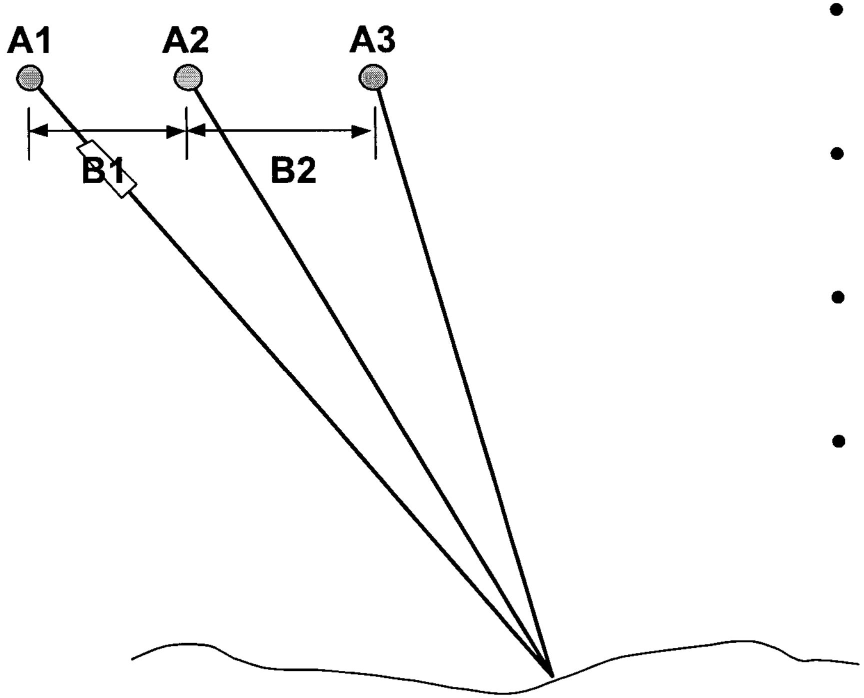
Resulting equations for measured phase ϕ, wavelength λ

$$\delta = \phi\lambda/2\pi \qquad (1)$$

$$\mathrm{Sin}(\alpha-\theta) = ((\rho+\delta)^{**}2 - \rho^{**}2 - B^{**}2)/(2^{*}\rho^{*}B) \qquad (2)$$

$$Z(x) = h - \rho\cos(\alpha)\cos(\alpha-\theta) + \rho\sin(\alpha)\sin(\alpha-\theta) \qquad (3)$$

Radar Interferometry
Theory of Combination Baseline Configurations



- Utilize multiple (>2) passes in near repeat orbit
- A1/A2 pass forms one interferogram
- A2/A3 pass forms second interferogram
- Topography fringes are scaled by B1/B2 and differential interferogram formed, canceling out topographic variation
- Residuals is motion of surface over time to subwavelength scale